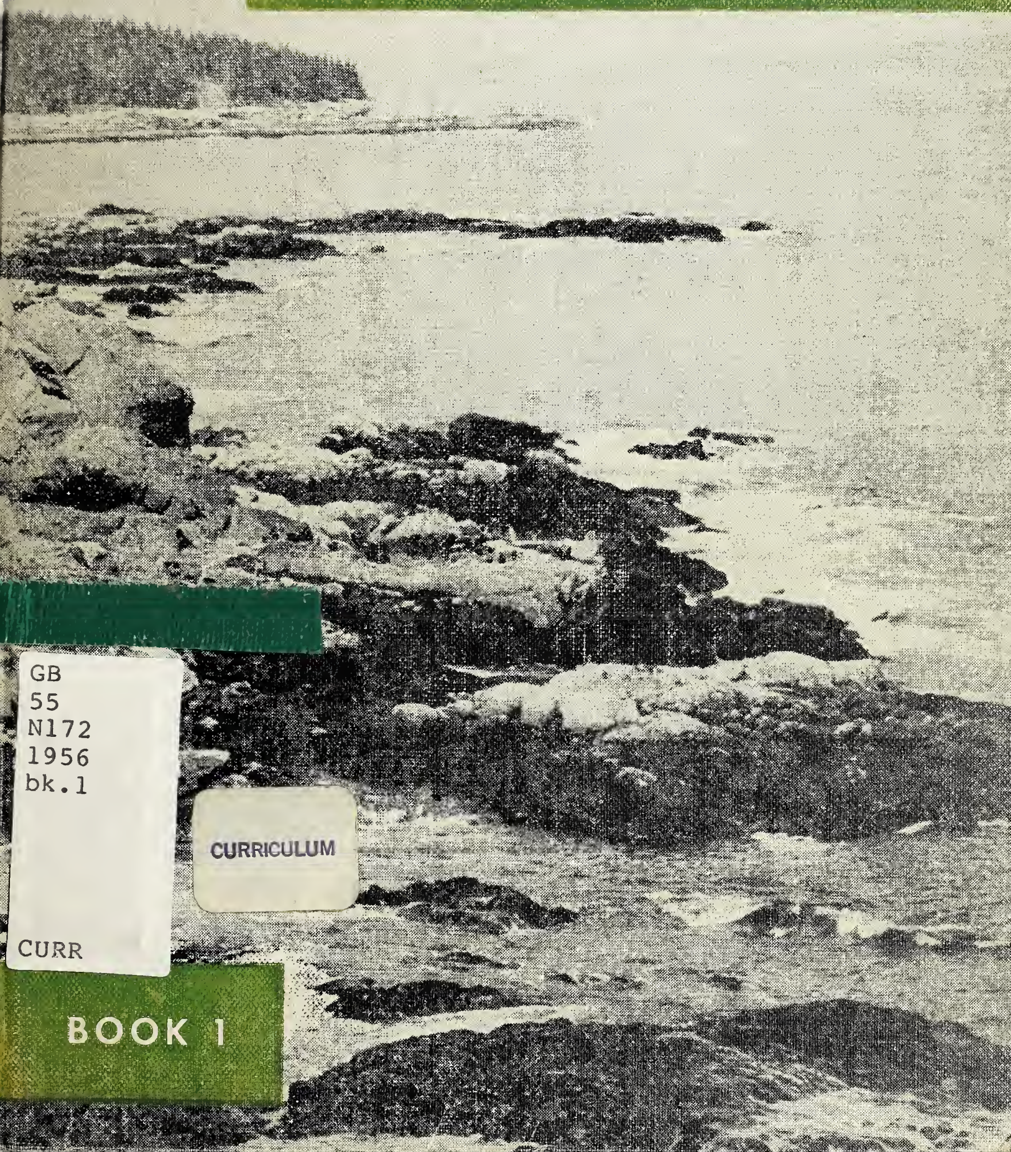
EARTH SCIENCE

THE WORLD WE LIVE IN

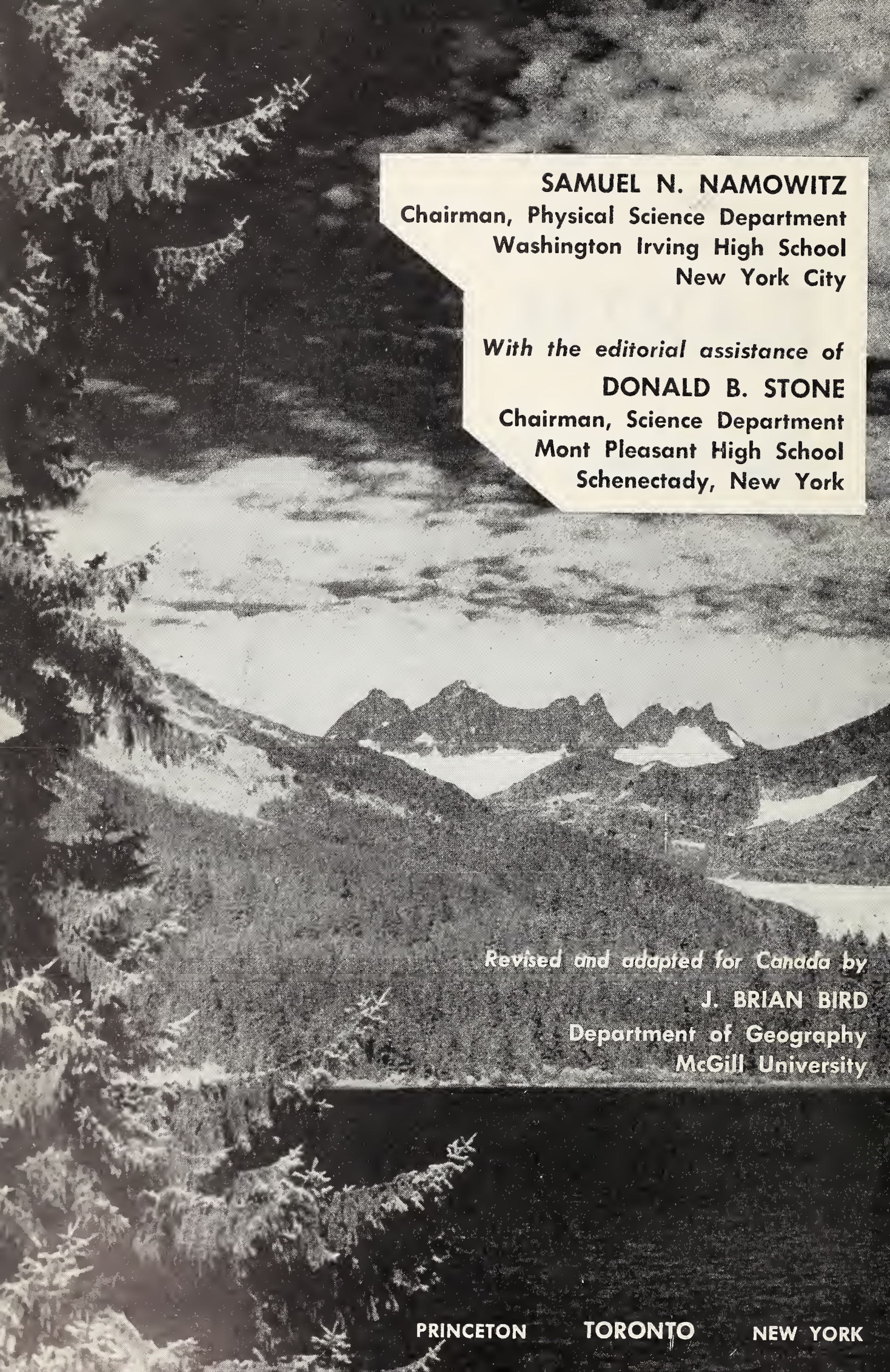


BOOK 1

EARTH SCIENCE

The World We Live In

BOOK I



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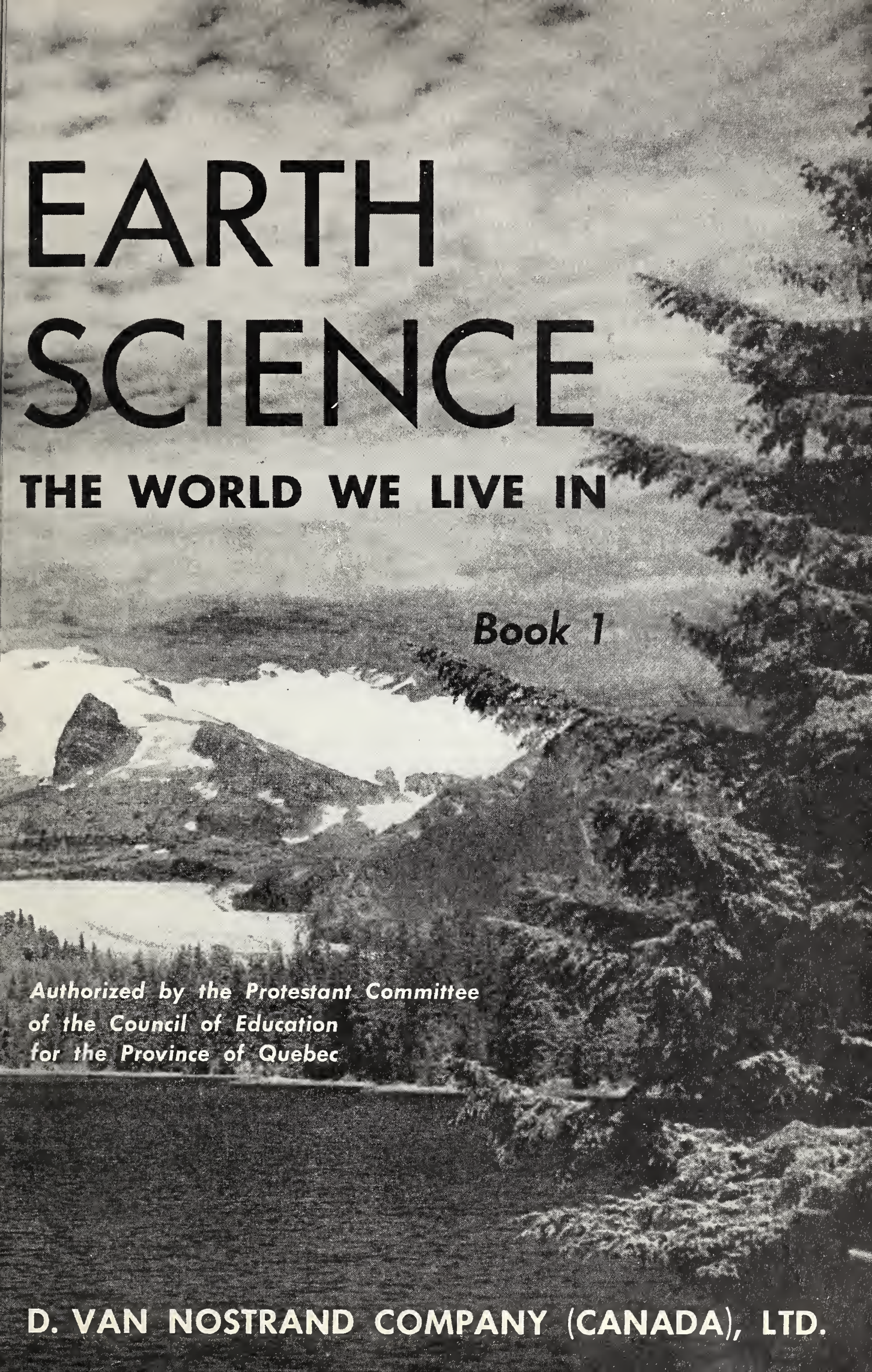

EARTH SCIENCE

THE WORLD WE LIVE IN

Book 1

Authorized by the Protestant Committee of the Council of Education for the Province of Quebec

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PREFACE

The Canadian edition of this book has been prepared because of the growing demand in Canadian high schools for books to deal adequately with man's physical environment. Although the processes and concepts discussed by the original authors are of worldwide application, the practical examples are more valuable to the student if they are drawn from places he has already visited or heard about; consequently where good Canadian examples of specific earth science phenomena exist they will be found in this edition. Two major alterations have been made from the United States edition. The original book has been divided into two separate books, the first dealing with geomorphology and astronomy and the second with oceanography, meteorology and climatology. The chapters, "Reading Topographic Maps" and "The Physiographic Provinces of Canada" are completely rewritten.

It is very largely as a result of the efforts of a committee of Montreal high school geography teachers, under the chairmanship of Miss Grace Fletcher, that the Canadian edition of this book has been produced. The reviser very gratefully acknowledges their suggestions, advice and encouragement.

July 1956 J.B.B.

PREFACE TO THE UNITED STATES EDITION

Earth science is the story of the world around us—the changing surface of the earth, the oceans and their shores, the atmosphere and its weather, and the heavenly phenomena in the universe. In brief, earth science is the story of man's physical environment.

Throughout this book, the author has aimed to develop *real* understanding of the processes and concepts with which earth science deals. The author has also sought to present basic ideas in sufficient detail to make them meaningful to high school students. A dogmatic approach has been avoided. There has been no compromise with completeness or adequacy in the treatment of topics that lie within the scope of this high school textbook.

Each chapter consists of several related *topics*, which are presented in such a way as to convey meanings rather than to require memorization. Important

technical terms are italicized and pronounced when first introduced in each topic. The number of technical terms has been kept to a minimum; only those necessary for a basic understanding of concepts and processes have been used.

At the end of each chapter, there is a series of *Topic Questions.* Each topic question, consisting of one or more parts, has been written specifically to cover the principal ideas discussed in the topic of the same number within the chapter. The teacher can therefore assign questions on the basis of the topics covered in the assignment. This arrangement also aids the student in locating the answers to the question.

Instead of chapter summaries, which by their very nature must be incomplete, the author has chosen to present this information in question form under the heading, *Have You Learned These?* The student is then asked to explain in his own words the principal points discussed in the chapter. Sheer memorization is thereby discouraged. The *General Questions* require the student to apply principles learned and to tie together major points discussed in several topics or chapters. These questions can be used to advantage in classroom discussion. The variety of testing aids, *Topic Questions, Have You Learned These?*, and *General Questions* provide a complete coverage of the major points in the book.

The *Student Activities* suggest laboratory exercises, experiments, experiences, or projects related to the work of the chapter. Some of these activities may be carried out in the classroom; others outside the classroom. *Supplementary Topics* for student research and reports have been selected as interesting outgrowths of the more elementary work of each chapter. In *Suggestions for Further Reading* will be found the references needed for the investigation of the supplementary topics.

The author is grateful to Mr. George McVey of John Adams High School, New York City, for his critical reading of the entire manuscript; to his many colleagues for practical suggestions and advice; to Aida C. Abramson for her expert clerical assistance; to Audrey Namowitz for her line drawings in this book.

September 1953 S.N.N.

Acknowledgment of Unit Photographs

Unit I. Grand Canyon. Courtesy Santa Fe Railway.
Unit II. Radar antenna used to transmit signals to the moon. Courtesy U. S. Army Signal Corps.

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UNIT I THE EARTH AND ITS LAND FORMS

UNIT II THE EARTH AND THE UNIVERSE

I. THE EARTH AND ITS LAND FORMS

What is earth science? The Northern Lights glow and shimmer mysteriously in the crisp cool air of a summer night. A meteor flares brilliantly against the blackness of an autumn sky. A tornado twists violently and destructively in a crazy path across the state of Arkansas. A volcano in the Philippines erupts without warning and destroys a village with all its inhabitants. A professional rainmaker showers a cloud with pellets of dry ice while other scientists on the ground send fire and smoke spiraling up into other clouds. The Niagara River plunges millions of gallons of water over a cliff 160 feet high every second, and every 65 minutes Old Faithful, a famous geyser in Yellowstone National Park, shoots a swirling, steaming fountain 150 feet into the air.

These are but a few examples of the subject matter included in the study of earth science. There are many branches of earth science, including such fields as astronomy, mineralogy, geology, oceanography, meteorology, climatology, and the many divisions of geography. The high school course in earth science, also often called *physiography* (fiz ee *og* ruh fee) or *physical geography,* is usually described as a study of the surface features of the earth. Used in a broad sense, the surface features include the land forms or scenic features of the earth, the oceans, and the atmosphere. The study of the origin of land forms is called *geomorphology* (jee oh mor *fol* uh jee). The study of the oceans is known as *oceanography* (oh shee uh *nog* ruh fee), and the study of the atmosphere includes both *meteorology* (me tee er *ol* uh jee) and *climatology* (kly muh *tol* uh jee). In addition, the high school course always includes a study of the earth in space, or *astronomy.*

Why study earth science? Some of you will use earth science in preparing to make a living—in forestry, agriculture, weather forecasting, mining, engineering, aviation, soil conservation, navigation, teaching, or scientific research. But all of you who study earth science will gain a wider understanding and a greater appreciation of the world in which you live. Features of the natural environment that were scarcely noticed before will capture your attention and raise many questions in your mind. The ability to explain these features will be a satisfying experience.

In studying earth science you will see the moon, the stars, and the planets with appreciative eyes; you will watch the changes of weather with interest and understanding; you will enjoy scenery even more because of your increased knowledge; you will "see" clearly floods, tornadoes, and volcanic eruptions that are described in the newspapers. Knowing that the earth takes up a relatively small amount of space in the universe, you will get new perspectives about the vastness of time and space.

Chapter 1

THE CHANGING SURFACE OF THE EARTH

1. Geomorphology. Let us begin our study of earth science with geomorphology, the study of land forms. It deals with volcanoes, earthquakes, and mountains; with waterfalls, cliffs, and canyons; with hot springs, geysers, and artesian wells; with rivers, lakes, and glaciers. It answers such questions as, How were the Great Lakes or the Rocky Mountains formed? What causes earthquakes? Briefly it explains the manner in which natural forces have shaped the surface of the earth into the great variety of land forms in existence today. The first half of the work in earth science is largely geomorphology.

2. The age of the continents. Almost three-fourths of the earth's surface is covered by oceans; only a little more than one-fourth of the surface stands above the level of the sea to form the continents. No one knows the exact manner in which the earth, born from the sun 5000 million years ago, cooled its outer crust into a wrinkled surface of ocean basins and continents. One fact, however, is certain. All the continents and ocean basins appear to have been in existence since the very beginning of earth history. Of course, they have undergone many great changes. There were times when the ocean waters receded some distance from their present shores, making the continents larger. There were other times when the oceans grew larger, covering areas of the continents that are dry land today, and sometimes even dividing continents into two parts (see Figure 1–1). But in every case, a substantial portion of each continent remained standing above sea level; in no case was a new continent formed from the ocean basins.

3. Surface features of the continents. The tourist who visits the scenic features of his country is likely to assume that they have existed since the beginning of time. He might be startled to learn that Niagara Falls is comparatively a new arrival; that the Grand Canyon, though millions of years old, is the product of a "young" river; that the Appalachian Mountains were on the earth long before the Rockies; and that the Canadian Shield is composed of rock as old as any in existence on this planet. Science has learned that the surface of the continents is always undergoing change, and today's scenery represents merely the present condition of that surface.

The earth scientist pictures the sur-

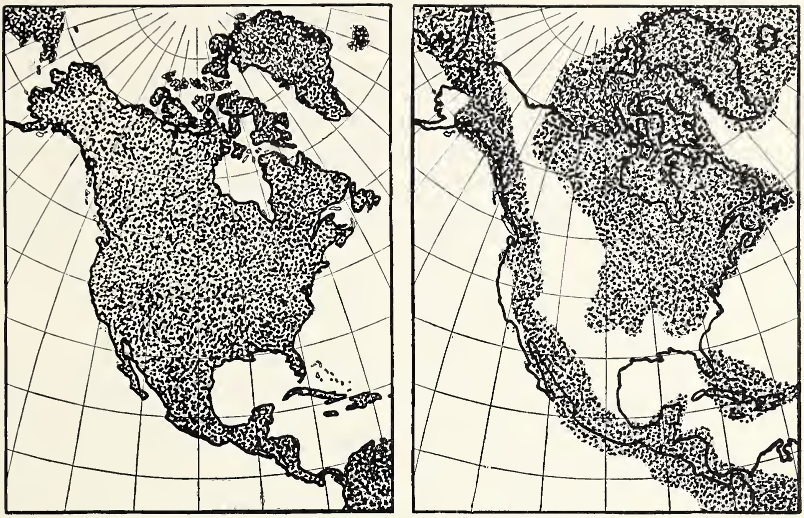

Fig. 1–1. At the left North America is shown as it is today. At the right it is shown as it appeared a hundred million years ago, divided into two parts by a great inland sea.

face of the continents as a battleground for two sets of opposing forces, one set that attempts to wear down and destroy the continents and another that raises and rebuilds them. The *destructional* forces, which receive their energy from the sun, include *weathering* and *erosion:* that is, the forces of weather, wind, waves, rivers, and glaciers. These forces are constantly attacking the rocks of the continents. In the billions of years of earth history, they could have worn the continents down to sea level many times over. They would have done so, had it not been for the *constructional forces,* which build up or raise portions of the continents at irregular intervals. The constructional forces, which originate in the earth's interior, include *vulcanism* (*vul* kun iz'm), or volcanic action, and *diastrophism* (dy *ass* truh fiz'm) or movements of the earth's solid rock crust, as in earthquakes. The conflict between construction and destruction has never ended in total victory for either side, although at various periods in earth history one or the other force may have been in the lead. The appearance of the continents at any moment merely represents the present state of the conflict between these two sets of natural forces.

4. Constructional and destructional forces. The earth scientist uses the words constructional and destructional in a way that is somewhat different from their ordinary usage. He regards any natural process that raises or builds up a portion of the earth's surface as constructional. When volcanoes pour out lava on the earth's surface and the lava hardens, the continent has been built up. Similarly, when a large block of the earth's solid rock is lifted up by forces inside the earth, the continent is built up. In the first case, the hot lava may cause great destruction of human life and property. In the second case, an

earthquake may do the same thing. Nevertheless, in the earth scientist's use of the term, both occurrences are constructional, for they build up the surface of the continents.

Again, the earth scientist regards winds, waves, rivers, and glaciers as destructional forces, since all their activities tend to wear the continents down to lower levels. This is true even when one of these destructional forces, such as a river, leaves a deposit of sand and clay at its mouth, building up a delta. This, says the earth scientist, is merely a temporary "build-up," as though a tired man were laying down his load for a moment before carrying it farther. The formation of a delta is simply part of the leveling process and is therefore not to be regarded as a truly constructional process.

5. Major and minor land forms. A physical map of Canada shows extensive areas which have such names as Western Cordillera, Interior Lowlands, and Canadian Shield written across them. These large mountains, plains and plateaus are *major land forms.* Similar types of rock and scenic features are found throughout a major land form. They have generally been created over long periods of geological time as a result of continuing constructional forces in the earth's interior.

Within any major land form, there are large numbers of smaller or *minor land forms.* The Gorge of the Fraser River, and the Rocky Mountain Trench are minor land forms in the Western Cordillera. They have resulted from the work of destructional forces attacking and eroding the major land form. Some of the minor land forms, including valleys, cliffs and caves are formed directly by erosion; others such as flood plains, deltas, sand bars, and many other features are formed by the deposition of material.

6. Planning the study of land forms. As part of his training, an engineer takes courses in strength of materials and blueprint reading. The first course gives him an understanding of the materials with which he is to work. The other course enables him to study many examples of the structures he must learn to build. Similarly, the earth scientist must know the strengths and weaknesses of the rocks that land forms are made of, and he must know how to read topographic (land form) maps. With this in mind, we plan our study of the origin of land forms in four steps. The first step will include a study of the rocks and minerals of the continents. The second step will describe the reading of topographic maps, or contour maps. The third step will deal with the work of weathering and erosion in making minor land forms. The fourth step will discuss the origin of major land forms through the work of constructional forces.

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. Explain what geomorphology means.

2. What changes have the continents, as a whole, undergone since the earth's origin?

3. How do most earth scientists believe the scenery of a continent originated? What is meant by "two sets of opposing forces"?

4. What does the earth scientist mean when he uses the words "constructional" and "destructional"?

5. Using examples, explain how land forms are classified. What forces produce each class?

6. Why do we study rocks, minerals, and contour maps before proceeding to study the origin of land forms?

SUGGESTIONS FOR FURTHER READING

Down to Earth, by Croneis and Krumbein. University of Chicago Press, 1936.

Our Amazing Earth, by C. L. Fenton. Doubleday, New York, 1938.

The Earth for Sam, by W. M. Reed. Harcourt, Brace, New York, 1941.

"The Changing Face of the Land," by Lincoln Barnett. *Life Magazine*, April 13, 1953.

Chapter 2

THE MINERALS IN THE ROCKS

1. From crust to core. Man's direct knowledge of the composition of the earth is confined to a very small portion of its total material. Although it is 4000 miles to the center of the earth, the deepest mines are less than 2 miles deep and the deepest wells are less than 4 miles deep. Nevertheless, by means of indirect methods man has obtained some idea of the nature of the earth from its surface to its center. Most of this information comes from studies of the manner in which the shock waves of an earthquake pass through the earth.

The earth appears to consist of three different parts. On the outside is a thin *crust* of comparatively light rocks about 25 or 30 miles thick, and about 2.7 times as heavy as water. Below the crust, an *intermediate zone* of much heavier rock extends halfway to the center, reaching a depth of about 2000 miles. Below the intermediate zone is the *core*, reaching 2000 miles more to the earth's center. This core is very hot (estimated at about 5500° F), under very great pressure (about 50,000,000 pounds per square inch), and very dense (about ten times as heavy as water). Some scientists believe that the core is composed largely of nickel and iron and is in a liquid state.

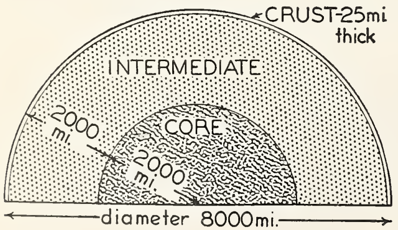

Fig. 2–1. A cross section of the earth from the surface to the center.

2. Bedrock and mantle rock. A large proportion of the earth's solid outer crust is hidden by a cover of loose rock, earth, or soil called *mantle rock.* This mantle rock may be the sand of a desert or beach, the boulders at the foot of a cliff, or the soil of farm, park, or forest. All of these are called mantle rock because they form a cover or mantle for the solid rock crust that lies beneath.

Mantle rock can be identified by the fact that it is loose material which can be dug up with a shovel or otherwise moved about. Below the mantle rock, in all parts of the earth, lies solid unbroken rock which can be penetrated only by drilling or blasting. This solid rock, which seems to be firmly attached to the entire thickness of all the rest of the earth, is called *bedrock.* Bedrock should not be confused with boulders, which are merely big blocks of solid rock

that lie on top of the bedrock but are not attached to it.

Mantle rock varies greatly in thickness. In some places it is hundreds of feet thick; in other places there is no mantle rock at all, and the bedrock is seen at the surface in *outcrops.* Outcrops of the bedrock are more likely to be seen in hilly regions than on level plains. Roads and highways often make cuts through small hills in which both the mantle rock and the bedrock can be seen.

3. Rocks and minerals. In any one locality, the same kind of bedrock is often found to extend over a considerable area. It may be any one of the many varieties of bedrock found throughout the world. Granite, slate, marble, and sandstone are examples of bedrock. Close inspection of these rocks shows that they are composed of definite substances called *minerals.*

Minerals like quartz (kwortz), mica (*my* kuh), calcite (*kal* syte), and magnetite range in size from tiny grains to pebble-size crystals, which seem to be cemented or melted together to form the rock. Some varieties of rock have only one kind of mineral in them; most varieties of rock contain two or more different kinds of minerals. To illustrate: limestone often consists only of the mineral *calcite;* granite always contains *quartz, feldspar,* and at least one other mineral.

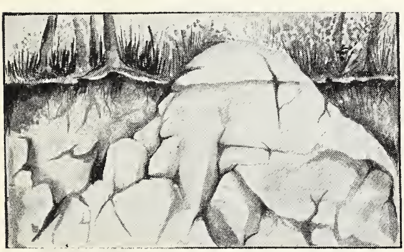

Fig. 2–2. The solid rock of the earth's crust is usually hidden by mantle rock. Bedrock that appears at the surface is called an outcrop.

Rocks may be compared to puddings, in which the minerals are like the ingredients of the pudding. The rock is the whole pudding; the minerals are the grains of rice, raisins, nuts, and other materials in the pudding. Just as raisins and nuts may be found in many kinds of puddings, so the same minerals may be found in many different kinds of rocks.

Minerals are inorganic substances of definite chemical composition that make up the rocks of the earth. (*Inorganic* means "not derived from living things.") Rocks are masses or mixtures of minerals, the composition of which may vary considerably.

4. Rock-forming minerals. Mineralogists have identified nearly 2000 different minerals in the rocks of the earth's crust. Many of these, like copper, gold, diamond, ruby, and uranium minerals, are found in comparatively few rocks, and even then in very small percentages. Others, like feldspar and quartz, are found in large numbers of rocks, and are likely to make up large percentages of these rocks. These common minerals are called *rock-forming minerals.* About 40 minerals fall into this group, and the first 10 of these make up more than 90 per cent of the earth's crust. To know how rocks behave, it is important to know something about the minerals of which they are made. After a general discussion of minerals, the more important rock-forming minerals will be described in Topic 10.

5. Identifying minerals. Because minerals are substances of definite chemical composition, they can always be identified by chemical analysis. But chemical analysis is slow, expensive, and not

suited to field work. The mineralogist has therefore worked out other methods of identifying minerals. Chemical analysis is used only when other methods fail. Minerals are usually identified by recognizing their physical properties through inspection and simple tests. One simple chemical test is also used frequently.

6. Identification by inspection. By examining a mineral, it is possible to see its color, luster, and crystal shape.

The *color* of a mineral often helps to identify it, but very few minerals can be identified by color alone. One reason is that many different minerals have similar colors, while others are colorless and transparent. A second reason is that even traces of impurities in a colorless mineral, for example pure quartz, may give it a variety of colors. The only minerals that can be identified by color alone are those that have only one color and never vary from it. Examples are cinnabar (*sin* uh bahr), a red mineral from which mercury is extracted, and malachite (*mal* uh kyte), a green mineral from which copper is extracted.

The *luster* of a mineral is its shine or lack of shine, which is produced by the way the surface of the mineral reflects light. Some common lusters are glassy, waxy, greasy, metallic, pearly, earthy, or dull.

If conditions are "favorable" at the time when the minerals develop in the rocks, the atoms or molecules of a mineral may arrange themselves in patterns which form flat-faced, regularly shaped solids called crystals. For example, the minerals galena (guh *lee* nuh), a lead ore, and halite, rock salt, form cube-shaped crystals; the mineral quartz forms six-sided prisms with pyramids at each end (see Figure 2–3). The shape of the crystal is therefore helpful in identifying a mineral. The crystals seen in rock

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Fig. 2–3. A group of quartz crystals.

specimens are often very small, so the mineralogist carries a hand magnifying glass with him. In many rocks, the mineral crystals can be seen only with a microscope, while in some cases the minerals have not formed crystals. Such minerals are said to be *amorphous*, that is, without form.

7. Identification of minerals by simple tests. The streak, cleavage, and hardness of a mineral can be tested very easily. The *streak* of a mineral is the color of its powder, and for many minerals it is not the same as the color of its crystal. Iron pyrites crystals are yellow, but their streak is greenish-black. Hematite is red or black, but its streak is always red. The streak is usually obtained by rubbing the mineral on a hard, rough, white surface like that of an unglazed tile or piece of porcelain, called a *streak plate*. Although the color of a mineral may vary greatly the streak rarely does.

The *cleavage* of a mineral is its tendency to split easily, leaving smooth flat surfaces. These flat surfaces are parallel to the flat faces of the crystals of the mineral. Mica splits very easily, always

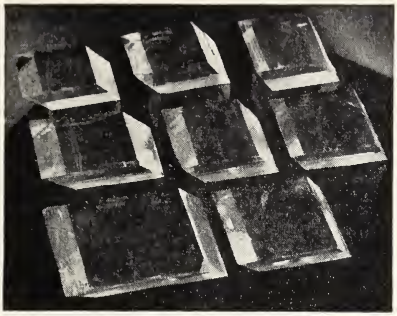

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Fig. 2–4. Calcite crystals plainly show the flat surfaces of the three cleavage directions of that mineral.

in the same direction, and is said to have one perfect cleavage. Feldspar splits readily in two different directions, at right angles or nearly so, and is said to have two good cleavages. Calcite and galena cleave in three directions. Not all minerals have cleavage. When minerals break along other than flat surfaces, they are said to have *fracture*. If the broken surface is smooth but curved, the mineral is said to have *shell-like fracture*. Flint has shell-like fracture.

The *hardness* of a mineral is usually judged by a scratch test. The diamond is the hardest of all because *it will scratch any other substance against which it is rubbed*. On the other hand, talc is the softest of all minerals, because all other minerals scratch it. For purposes of comparison, the mineralogist uses a standard scale of hardness consisting of these ten minerals, arranged from softest to hardest:

Mineral	*Simple Test*
1. Talc	1. Fingernail scratches it easily.
2. Gypsum	2. Fingernail barely scratches it.
3. Calcite	3. Copper penny just scratches it.
4. Fluorite	4. Steel knife scratches it easily.
5. Apatite	5. Steel knife scratches it.
6. Feldspar	6. Steel knife does not scratch it; it scratches window glass easily.
7. Quartz	7. Hardest common mineral; it scratches steel and hard glass easily.
8. Topaz	8. Harder than any common mineral (it is a semi-precious stone).
9. Corundum	9. It scratches topaz.
10. Diamond	10. Hardest of all minerals.

It is easy to see that with a copper penny, a knife blade or nail file, and a small glass plate, one can determine the approximate hardness of any common mineral. If a mineral is harder than number 5 but softer than number 6 in the hardness scale, it may be said to have a hardness of about 5½. Hardness should not be confused with brittleness. Glass is a brittle substance which breaks easily when dropped, but it is much harder than copper and many other metals.

8. The acid test. Calcite, a fairly common mineral which is the principal constituent of limestone and marble, is easily identified by a simple chemical test. Calcite is a compound of calcium, carbon, and oxygen. Its chemical name is calcium carbonate. If a drop of cold dilute hydrochloric acid is placed on calcite, the drop of acid effervesces as bubbles of carbon dioxide gas are given off. Calcite is the only common mineral which reacts in this way. (Dolomite, a carbonate of calcium and magnesium, does not react with cold dilute acid.)

9. Elements in the earth's crust. An *element* is a substance which cannot be broken down into any simpler substances by ordinary chemical means. Atom smashing or atomic fission would not be considered ordinary chemical means. Oxygen, hydrogen, and carbon are examples of nonmetallic elements; iron, gold, and uranium are examples of metallic elements. Some minerals in the

earth's crust, such as sulfur, diamond, copper, gold, and a few others, are composed of only one element, but most minerals are compounds of two or more elements. Chemical analysis of thousands of mineral samples shows that they contain altogether no more than ninety-two different elements (new elements have been created by chemists, but they are not found in minerals).

Eight of these elements are so much more abundant than the rest that they compose nearly 99 per cent by weight of all the earth's crust. The most abundant element is *oxygen*. Oxygen is always found in combination with other elements. It alone makes up almost half the weight of the rocks. Silicon is next in abundance, forming about one-fourth the weight of the rocks. Both of these elements are nonmetals, but the next six in order are metals. Metals, including such familiar elements as gold, silver, iron, copper, lead, and aluminum, are easily recognized by their high luster, their ability to conduct heat and electricity, and their ability to be hammered into sheets or drawn into wire. Nonmetals do not have these properties. Sulfur, oxygen, and phosphorus are common nonmetals.

The Eight Most Abundant Elements in the Earth's Crust

Name	*Chemical Symbol*	*Per cent by Weight*
Oxygen	O	46.71
Silicon	Si	27.69
Aluminum	Al	8.07
Iron	Fe	5.05
Calcium	Ca	3.65
Sodium	Na	2.75
Potassium	K	2.58
Magnesium	Mg	2.08

10. Knowing the rock-forming minerals. *Feldspar*, the most abundant of all minerals, is found in more kinds of

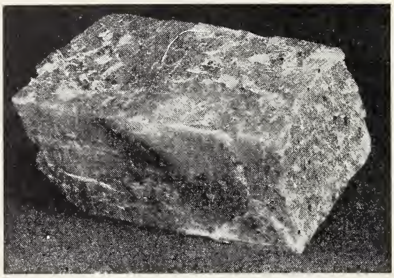

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Fig. 2–5. A specimen of orthoclase feldspar. The two larger surfaces represent the two cleavage directions that are at right angles to each other.

rock than any other mineral. There are many varieties of feldspar, but all of them have two good cleavages—at or nearly at right angles to each other—and are about number 6 in hardness. The commonest colors are white, gray, and pink, but almost any color is possible. Feldspar is a constituent of all granite rock, where it is easily identified by its color and smooth cleavage surfaces. The two commonest varieties of feldspar are called orthoclase feldspar and plagioclase (*play* jee o klaz) feldspar. Orthoclase (*or* thuh klaz) has the chemical formula $KAlSi_3O_8$ (potassium aluminum silicate) and cleaves exactly at right angles. Plagioclase feldspar contains sodium or calcium instead of potassium, and its cleavages are not exactly perpendicular to each other. Orthoclase is of considerable commercial importance in the making of porcelain, china, and scouring powders.

Quartz is next to feldspar in abundance. Pure quartz has the chemical formula SiO_2 (silicon dioxide), is colorless or white, and has a rough or shell-like fracture but no cleavage. At number 7 in the scale of hardness, quartz is the hardest common mineral. Small traces of other elements in quartz may

give it a variety of colors. Some of the different kinds of quartz are rock crystal (colorless), milky quartz (white), rose quartz (pink), amethyst (purple), smoky quartz (gray-brown), agate (colored bands), and flint (gray). The rocks sandstone and quartzite are composed mainly of quartz grains or crystals, and granite always includes quartz. Most sands are simply fragments of quartz. Commercially, quartz crystals are used as semi-precious stones and as the "crystals" in radio and television transmitters. Quartz sand is used in making glass, concrete, and sandpaper. Sandstone is a common building stone and grindstone.

Mica is easily identified by its occurrence in thin, shiny, flat plates or flakes in granites, some sandstones, and many other rocks. It has one excellent cleavage and a hardness of about 2.5. The principal varieties of mica are the silvery-white *muscovite* and the black or dark brown *biotite*. The micas have very complex formulas, including Al (aluminum), Si (silicon), O (oxygen) combined with varying amounts of Fe (iron), Mg (magnesium), H (hydrogen), and K (potassium). Like the feldspars, they are aluminum silicate compounds. Muscovite is commonly known as isinglass. It may be seen in thin sheets in electric toasters and furnace-door windows.

Calcite has the formula $CaCO_3$ (calcium carbonate). Pure calcite is colorless or white, has three good cleavages, and is number 3 in hardness. When impure, calcite may occur in many different colors. It is easily identified by the acid test described in Topic 8. Clear calcite crystals have the property of double refraction. When an object is looked at through such a crystal, two images are seen instead of one. Calcite is the chief mineral in limestone and marble. Limestone is used in the making of cement, mortar, and glass, in the smelting of iron ore, and as a building stone. Marble is used as a building and monumental stone.

Hornblende is a common mineral having two good cleavages, a hardness between 5 and 6, and colors ranging from dark green through brown and black. It occurs frequently in the igneous and metamorphic rock groups. (Igneous rocks are formed from hot lava. Metamorphic rocks are rocks that have been changed by heat, pressure, and chemical action. See next chapter for complete explanation.) Like mica, hornblende is a complex aluminum silicate mineral.

Kaolin or *kaolinite* is a very soft, smooth mineral with a dull luster. It is the chief constituent of clay and the rock called shale. Pure kaolin is white, but impurities usually color it yellow. It may also have reddish, brownish, greenish, or bluish tints. Its hardness is usually less than 2. Kaolin is formed largely by the decomposition of feldspar. Like feldspar, it is used in making china, porcelain, tile, and brick. It is often called *china clay*. Its chemical formula is $H_4Al_2Si_2O_9$.

Augite (*au* jyte), the commonest variety of a family of minerals called *pyroxenes*, is found in many igneous and metamorphic rocks. Like hornblende, it is dark green, brown, or black in color, has a hardness between 5 and 6, and has two good cleavages. But it can be distinguished from hornblende by its poorer luster, its different crystal shape, and its nearly vertical cleavage angles. It is a complex aluminum silicate mineral.

Garnet is the name of a family of minerals also common to the igneous and metamorphic rocks. Their hardness ranges from 6.5 to 7.5, their luster from glassy to waxy, and their color through dark red, brown, green, and black. Clear

crystals are used as gems; poorer ones are crushed for use in such abrasives as garnet paper. Chemically, garnets are aluminum silicates combined with iron, calcium, or other metallic elements.

Magnetite is a magnetic iron oxide, Fe_3O_4. Both its color and streak are black. (Hematite, another iron ore which may be black, has a red streak). Magnetite has a metallic luster, and its hardness ranges from 5.5 to 6.5. It commonly occurs in igneous rocks in the form of small crystals. When found in large quantities, it is an important iron ore. Its name is derived from the fact that it is attracted to a magnet. *Lodestone*, a natural magnet from which the first magnetic compass needles were made, is a highly magnetic variety of magnetite.

Olivine is a yellowish-green mineral which occurs in many dark-colored igneous rocks such as in the Palisades of New Jersey. It has a glassy luster, shell-like fracture, and hardness between 6.5 and 7. Clear specimens are used as gem stones.

Pyrite or *iron pyrites* is a pale brass to golden yellow mineral with a greenish-black streak. Because of its golden color and high metallic luster, it has been mistaken for gold and is known as fool's gold. Its hardness is about 6. Large deposits of pyrite are mined for use in the manufacture of sulfuric acid. Pyrite is iron sulfide, or FeS_2. The commonest of all sulfur compounds in the earth, it occurs in many varieties of rock.

11. Minerals and ores. All metals, as well as many important nonmetals, are obtained from minerals in the rocks of the earth. These metals and nonmetals sometimes occur in native form, or uncombined with other elements, and need merely to be broken apart from the other minerals in the rock. Gold, copper, silver, platinum, sulfur, graphite (carbon), and diamond (carbon) are the most important native minerals. More commonly, however, elements occur combined with other elements and must be chemically extracted before they can be used. In either case, whether the desired element is found free or in combination, it usually forms only a small percentage of the rock in which it is found, and has to be separated from the rock. When the rock contains enough of the valuable mineral to make the separation worth while, it is called an *ore*. Thus we speak of iron ore, copper ore, and sulfur ore. The term ore is most often applied to metallic deposits, but can also be used for nonmetals.

Ores may occur as rich mineral *veins* running through rock masses; in other cases an entire rock mass is rich enough in a mineral to form an ore. Native minerals like gold and diamonds often occur in loose *placer deposits* of gravels and sands found in river beds or on ocean beaches. Apparently the rock that originally contained the precious mineral, after being broken up by weathering and erosion, was carried to its present location by rivers or waves. The gold rushes to British Columbia in 1858 and to the Klondike in 1897 were caused by the discovery of rich placer deposits.

12. Important metallic minerals. *Iron* is obtained chiefly from the minerals magnetite, limonite, and hematite, which are compounds of iron and oxygen. *Magnetite* is black, has a black streak, and is attracted by a magnet. *Limonite*, similar to iron rust, contains water and may be light brown to black in color. Its streak, however, is always yellowish-brown. *Hematite*, the most important iron ore, is black or red in color, but always gives a red streak.

Copper is obtained in the free state or from chalcocite (*chalco*, copper), chalcopyrite, azurite, and malachite. *Chalcocite* is a compound of copper and sulfur, dark gray to black in color. *Chalcopyrite* (copper pyrite) is a compound of copper, iron, and sulfur. Like iron pyrites, its color is golden yellow and its streak is greenish-black. However, it is much softer than pyrite, and slightly darker. *Azurite* and *malachite* are both copper carbonates. Azurite is blue, malachite is green.

Aluminum is obtained from bauxite (*bawks* yte), a compound of aluminum and oxygen that may be white, yellow, brown, or reddish in color.

Lead is obtained from galena, a compound of lead and sulfur that is easily identified by its cube-shaped crystals and its lead-gray color.

Zinc is obtained from sphalerite, a compound of zinc and sulfur that has a waxy luster and a variety of colors including yellow, brown, black, green, and red.

Tin is obtained from cassiterite, a compound of tin and oxygen that is usually reddish brown, brown, or black in color.

Uranium and *radium* are obtained from uraninite (also called pitchblende) and carnotite, both of which are oxides of uranium and other elements.

All the ore minerals described above occur plentifully in Canada, except for the ores of aluminum and tin. Most of the world's supply of tin comes from Malaya, Indonesia, and Bolivia; a little is found in northwest Canada. The largest deposits of aluminum ore are in British Guiana, the West Indies and Hungary.

13. Some nonmetallic minerals. *Sulfur* occurs as a native mineral in limestone or gypsum rock, in volcanic areas, and around some hot springs. It is used in the manufacture of sulfuric acid, vulcanized rubber, matches, gunpowder, various types of insecticides, bleaches, and paper.

Carbon occurs in native form as *diamond*, hardest of all minerals, and graphite. Diamonds are colorless when pure, but they have color when they contain impurities. Most of the world's supply of diamonds comes from the volcanic rocks of the Kimberley Mines in South Africa, although some have been found in placer deposits. Clear stones are used as gems; poorer ones are used for drilling and polishing very hard materials. Graphite is a fairly common mineral in metamorphic rocks. Large deposits of graphite are mined for use in making "lead" pencils, lubricants, crucibles, electrodes, and paint. Graphite is very soft, and has a greasy feel. It withstands the highest temperatures without melting or burning and is not affected by acids.

Talc, softest mineral in the scale of hardness, is white, gray, or greenish. It is ground up to make talcum powder. As *soapstone*, it is used in laboratory tables and in electrical switchboards. The formula of talc is $H_2Mg_3Si_4O_{12}$.

HAVE YOU LEARNED THESE?

Meanings of: mantle rock, bedrock, rock, mineral, amorphous

Descriptions of: outcrop, the earth's interior, rock-forming minerals, physical properties of minerals, the acid test, placer deposits, ores

Explanations of: determining the hardness of a mineral; the relation between rocks and minerals

Names of: the eight most abundant elements in the earth's crust and their approximate percentages

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) What are the direct and indirect sources of information about the composition of the earth? (*b*) Describe the composition of the earth from its surface to its center.

2. Explain what is meant by mantle rock, bedrock, boulders, and outcrops. Give some illustrations from your own locality.

3. (*a*) Explain the relation between rocks and minerals. (*b*) Define both.

4. Explain what rock-forming minerals are and how they compare in number and percentage with all other minerals.

5. Why are minerals usually identified by their physical properties rather than by chemical analysis?

6. (*a*) Why is it difficult to identify a mineral by its color alone? (*b*) What is meant by luster of a mineral? Name the different types of luster. (*c*) What is a crystal? How does crystal shape help to identify a mineral? What are amorphous minerals?

7. (*a*) What is the streak of a mineral? How is it obtained? (*b*) What are cleavage and fracture? Give examples. (*c*) Explain what hardness is. How is it determined?

8. What is the acid test for calcite?

9. Explain what an element is. List in order the eight most abundant elements in the earth. Classify each as metal or nonmetal. What are the properties of metals?

10. Give brief descriptions of a few rock-forming minerals. (Ask your teacher which ones you should describe.)

11. Explain what is meant by native minerals, extracted, ores, and placer deposits.

12. Name at least one ore mineral of each of the metals listed in this topic.

13. Describe the occurrence and uses of three important nonmetallic minerals.

GENERAL QUESTIONS

1. Using a copper penny, a pen-knife, and a square of ordinary window glass, how would you show that the hardness of each of these minerals was about as indicated: (*a*) hornblende, 6; (*b*) mica, 2½; (*c*) augite, 5½; (*d*) garnet, 7½; (*e*) kaolin, 1½; (*f*) sphalerite, 3½?

2. From the lists of minerals given in Topics 10 and 12, select two that have the same color but different streaks.

3. Are tooth powders harder or softer than tooth enamel? Explain.

4. Should chalk be harder or softer than slate? Explain.

5. Why are diamond glass cutters so much better than those made of steel?

6. What caused the shortage of tin in North America during World War II?

STUDENT ACTIVITIES

1. Making a collection of rock-forming minerals, of ores and ore minerals, and of minerals illustrating hardness, luster, cleavage, and crystal shape

2. Studying the physical properties of common minerals

3. Determining the specific gravities of minerals

SUPPLEMENTARY TOPICS

1. How Earthquake Waves Provide Information about the Earth's Interior
2. Crystal Forms in Minerals
3. Mineral Lusters
4. The Occurrence of Metallic Ores in Canada
5. The Gold Ores of South Africa
6. Diamond Mines

SUGGESTIONS FOR FURTHER READING

Getting Acquainted with Minerals, by G. L. English. McGraw-Hill, New York, 1936.

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Dana's Manual of Mineralogy (revised by Hurlbut), by W. E. Ford. Wiley, New York, 1941.

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Field Book of Common Rocks and Minerals, by F. Loomis. Wiley, New York, 1923.

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Chapter 3

THE BEDROCK OF THE CONTINENTS

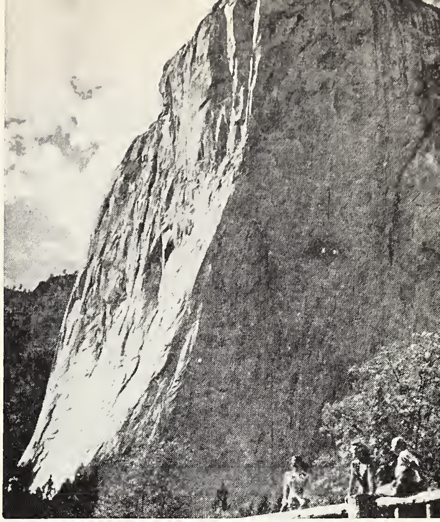
1. The arrangement of bedrock. Wherever the bedrock outcrops at the surface, its arrangement or structure can be studied. Outcrops may occur on mountain tops, at the faces of cliffs, in canyons carved out by rivers, or in fields where the mantle rock fails to cover the bedrock. In all outcrops, two principal arrangements of bedrock can be noticed. In one, the rocks are arranged in horizontal or nearly horizontal layers, and are described as *stratified* rocks (*strata*, layers). The layers may differ from one another in color, smoothness of appearance, or in other respects. On close inspection they are also seen to be composed of different kinds of rock, or of similar rocks with slight variations in mineral content or size of particle. The layers, which are as plainly separated as

Canadian Pacific Railway

Fig. 3–1. Horizontal sedimentary rock strata in the gorge of the Niagara River.

the layers of a cake, may vary in thickness from a mere fraction of an inch to many feet. They split away from each other with varying degrees of difficulty. Good examples of stratified rock are seen in the exposed cliffs of Niagara Falls and the upper sections of the Grand Canyon of the Colorado River (see Figure 3–1).

In the other common structure of bedrock, the rock appears to be all of one kind from top to bottom of the outcrop, even for thousands of feet. Such rock is described as *massive* or *unstratified.* Massive rocks form a great part of the Canadian Shield and may be seen throughout the Muskoka Lakes and Laurentian districts.



Courtesy Santa Fe Railway

Fig. 3–2. Massive or unstratified rock forming the great cliff known as El Capitan in Yosemite National Park, California.

2. The origin of the rocks. The bedrock of the earth's crust is most commonly classified according to origin into three groups. *Igneous* (*ig* nee us) rocks are those formed by the cooling and hardening of hot molten rock from within the earth's crust. *Sedimentary* (*sed* uh *m'n* tehr ee) rocks are those formed by the hardening of sediments derived from other rocks. *Metamorphic* (met uh *mor* fik) rocks are formed when rocks that already exist are transformed directly into new kinds of rock. The solidified lava of a volcano is igneous; sandstone, formed of sand, is sedimentary; marble, derived from the transformation of limestone, is a metamorphic rock. Each of these groups will now be studied more fully.

3. Where igneous rocks form. The hot liquid rock material from which igneous rocks are formed is called *magma.* Igneous rocks are often divided into two groups, according to the place *where* their magma solidifies. *Extrusive* (or *eruptive*) igneous rocks are formed when the magma forces its way onto the earth's surface by erupting through volcanoes or fissures in the earth's crust. The erupted magma is commonly called *lava* (*lav* uh). *Intrusive* (or *plutonic*) igneous rocks are formed when the magma forces its way into or between masses of rock below the earth's surface. There it hardens slowly. Pumice, obsidian, scoria, and basalt are extrusive igneous rocks. Granite, diabase (*dy* uh bas), and gabbro (*gab* broh) are intrusive igneous rocks.

4. Crystalline or glassy rocks? Magmas are simply very hot mixtures of melted minerals. As a magma cools, its various minerals tend to separate from the mixture in the form of crystals. Some minerals crystallize faster than others. Hornblende and biotite, for example, crystallize sooner than do feldspar and quartz. *The longer the magma takes to cool, the larger its crystals become.*

The rate of cooling of a magma depends chiefly on its distance from the earth's surface. Magmas that cool deep within the earth's crust cool very slowly,

forming intrusive rocks with large, easily visible crystals or grains. Such rocks, like granite and gabbro, are said to be *coarse-grained* in texture. (As with cloth, texture refers to the "weave" of the rock, or the size and arrangement of its particles.) Magmas that cool close to or on the surface cool more rapidly, forming rocks with tiny crystals that are usually too small to be distinguished without a microscope. Such rocks, like felsite and basalt, are said to be *fine-grained* in texture. Erupted magmas may also cool so rapidly that there is no time at all for crystals to develop, and the rocks that form are as smooth as glass. Such rocks, like obsidian, are said to be *glassy* in texture.

The same magma, cooling at different distances from the surface, may form rocks very different in appearance, *although their mineral composition is exactly the same*. For example, a magma containing quartz, orthoclase feldspar, and biotite mica may cool very slowly to form light-colored, *coarse-grained granite*; if it cools faster, it will form a light-colored *fine-grained* rock called *felsite*; if it cools very quickly it will form a *glassy* rock such as *obsidian* or *pumice* (*pum* iss). A magma containing plagioclase feldspar and augite may cool very slowly to form a dark-colored, *coarse-grained* rock called *gabbro;* if it cools faster it will form a dark-colored, *fine-grained* rock called *basalt* (buh *sawlt*); if it cools very fast it will form a *glassy* rock such as *obsidian* or *pumice*. Glassy rocks are comparatively rare, and the large majority of igneous rocks are crystalline.

5. Knowing the igneous rocks. There are many varieties of igneous rocks, but the seven described here are among the most familiar. The first four in this list are extrusive; the others are intrusive.

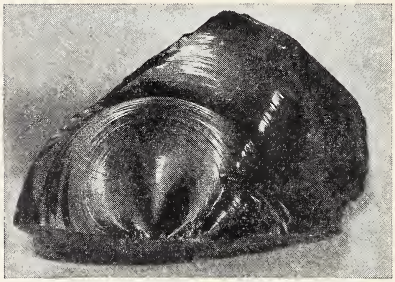


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Fig. 3–3. Obsidian, showing glassy texture, shell-like fracture, and sharp edges.

Obsidian, formed by the rapid cooling of surface flows of lava, is usually dark brown to black in color and glassy in texture. Known as volcanic glass, it is very hard but breaks easily with a shell-like fracture that leaves very sharp edges. Primitive peoples fashioned it into arrowheads, knives, hatchets, and other implements. Obsidian Cliff in Yellowstone National Park is one of its best-known occurrences.

Pumice is the name given to lava that solidified while steam and other gases were still bubbling out of it, forming rock that looks like a sponge with many fine holes in it. Pumice is usually light gray, while its air holes often make it light enough to float. It is sometimes seen on the ocean after the eruption of an island volcano.

Scoria is similar to pumice in origin, but its holes are larger. It is usually much heavier than pumice.

Basalt, one of the commonest of the rocks formed from flows of lava, is dark gray to black and fine-grained in texture. Its tiny crystals must be magnified before they can be identified as augite, feldspar (a dark variety), and frequently olivine. Basalt is found in the lava flows of the Canadian Western Arctic and northwestern United States.

Diabase, cooled a short distance below the earth's surface, is similar to basalt in

color and minerals, but is slightly coarser in texture. Known also as *trap rock,* it forms the upland on the north side of the Annapolis Valley in Nova Scotia, and the Palisades along the lower Hudson River.

Granite and *gabbro* are intrusive rocks that were formed by very slow cooling far from the surface, under thousands of feet of other rocks. They both contain large crystal grains of easily recognizable minerals. *Granites* always contain quartz, feldspar, and at least one other mineral such as mica or hornblende. The quartz grains look like little chips of cloudy or grayish glass; the feldspar crystals can be recognized by their smooth cleavage surfaces and by their color, such as white, gray, or pink. The mica flakes, usually black, can be chipped out with the fingernail. Hornblende, also black or dark green, occurs in small chunks or sticks that cannot be removed so easily. Granites vary in color from light grays to medium grays and pinks, with the feldspar having the greatest influence on the over-all color.

Granite is the most abundant of all igneous rocks. It can be seen in the Rockies and the Canadian Shield where it probably forms more than four-fifths of the whole area. Its presence at the surface indicates that erosion has removed thousands of feet of other rocks that once covered the now exposed granite.

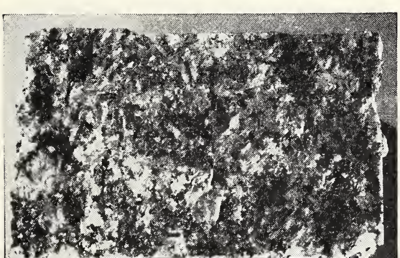

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Fig. 3–4. Granite, showing its coarse-grained texture. The dark mineral is biotite mica. The light minerals are quartz and feldspar.

Gabbro, like basalt, is dark gray to black and composed of augite and a dark feldspar, but its crystals are much larger. It is one of the more common intrusive rocks after granite. It forms the greater part of the Monteregian Hills in the St. Lawrence Lowlands.

With the exception of pumice and scoria, the rocks formed from lava or magma have almost no pores or spaces in them, and are described as nonporous.

6. Grouping the sedimentary rocks. Sedimentary rocks were defined as rocks formed by the hardening of sediments derived from other rocks. They are usually divided into three groups according to the origin of the sediments in them. *Mechanical sediments* are simply pieces or fragments of other rocks, such as pebbles, sand, and clay. *Organic sediments* are the remains of plants and animals. Shells and ferns are examples of organic sediments. *Chemical sediments* are minerals that were once dissolved in water. Rock salt, gypsum, and geyserite are examples of chemical sediments.

7. How fragments turn to rock. When rocks are broken up by weathering and erosion, they form fragments of all sizes—boulders, pebbles, gravels, sands, silts, and clays. Pebbles and sands do not need to be defined. Boulders are simply pieces of rock larger than pebbles. Clay is very finely powdered rock or mineral material. Silt is coarser than clay but finer than sand. When clay and silt are dry, they are easily blown into the air as dust; when wet, they form mud. Gravel is the name given to a mass of small round pebbles or to a mixture of such pebbles with sand.

These rock fragments, or *sediments,* sliding down mountainsides, dragged away by glaciers, washed off by rains, rivers, or waves, or blown into the air by winds, are often carried to places where they pile up in tremendous quantities. The largest accumulations of sediments are in the shallow-water areas of lakes and oceans into which rivers flow. (The shallow ocean areas that border the continents are called the continental shelves.) The sediments that the rivers drop on the continental shelves and lake bottoms are said to be *deposited.* When these deposits of pebbles, sands, silts, or clays become hundreds of feet thick, their lower layers may harden into rock. Two processes seem to be responsible. In fine materials like clay and silt, the tremendous pressure on the bottom layers makes the particles stick together. In coarser sediments like sands and gravels, the particles do not hold together unless they are cemented. But ocean and lake waters contain dissolved minerals such as silica (quartz), lime (calcite), and limonite which are natural cements. These minerals may be chemically deposited between the fragments of sands and pebbles, cementing them into rock. Silica and lime cements are usually white; limonite is yellowish or rust-colored.

8. Separating the sediments. When a river flows into a lake or ocean, it drops its sediment as it gradually loses its speed. The first sediments to be dropped are the heavy gravels, which settle to the bottom in the shallow waters of the continental shelves nearest to shore. Next come the sands, and finally the silts and clays. *This separation of sediments by size is called assortment.* The process of assortment may not produce perfect separation; sand may be found mixed with the gravels in shallow water, as well as with silts and clays in deeper water. Nevertheless, the deposits are fairly definite. As the sediments harden, the gravels form a rock called *conglomerate,* the sands form *sandstone,* and the silts and clays form *shale.* When clays contain a large amount of lime, they are called *marl.* Marl forms a *limy shale.*

9. Conglomerate, sandstone, and shale. *Conglomerate* may contain any kind of pebbles, but quartz pebbles are commonest. The pebbles are usually mixed with sands that help to bind them together and give conglomerate the appearance of man-made concrete. Some conglomerates are very tough, durable rocks. Others are so poorly cemented that they can be broken apart by hand.

Sandstone, too, may be composed of any kind of sand grains, but most sandstones are made largely of grains of quartz. Although the grains are cemented together, the cement never fills all the spaces between the grains, and sandstones may have up to 30 per cent

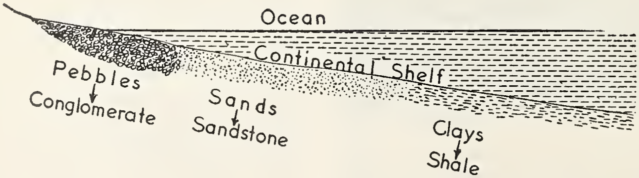

Fig. 3–5. Sediments deposited on a continental shelf are compressed and cemented into sedimentary rocks.

of air space in them. For this reason they are *porous*, and, since water can pass through them, they are also said to be *pervious* or *permeable*. Sandstones are hard and rough. They occur in a variety of colors, white, gray, red, and brown. The color of sandstones depends to a large extent on the mineral that cements the grains together. Impure sandstones may contain a large proportion of clay or lime.

The clays that make up *shale* are usually composed of the mineral kaolin, although many other minerals may be mixed in. The pore spaces in shale are so tiny that water is unable to pass through the rock. The rock is then said to be *impervious* or *impermeable*. In this respect, shale is unlike sandstone. Because of their very fine particles, shales are smooth. They are comparatively soft and easily broken. Shales, like clays, occur in almost all colors. Black or dark gray shales appear to owe their color to carbon from decayed plant material. Fossils are often found in shales.

10. Why sedimentary rocks form layers. When any change occurs in the kind of sediments that are being deposited in one place, new rock layers are

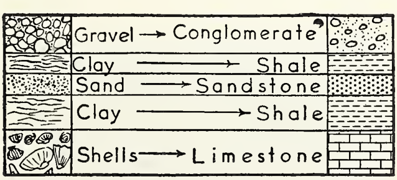

Fig. 3–6. The formation of layers in sedimentary rocks. New layers are formed as different sediments are deposited. As the sediments shown at the left are cemented, they form the rock layers shown at the right. (The symbols shown on the right are regularly used to represent these rocks in geologic diagrams.)

formed. For example, if a coarse clay is deposited on a fine one, or a yellow clay on a white one, different layers of shale will form, one on top of the other. On the other hand, if sand is deposited on clay, a layer of sandstone will form on a layer of shale. In this way sedimentary rocks become *stratified*.

Sediments change for many reasons. The river that brings the sediment to the ocean may be wearing away new kinds of rock; it may carry larger quantities and more varieties of pebbles, sand, and clay during flood times; it may carry its sediments farther out to sea than formerly or drop them closer to shore. These and many other events are responsible for changes in the nature of the sediments left at any one spot.

11. How fossils form. As sediments pile up on continental shelves, lake bottoms or swamp floors, animals that live

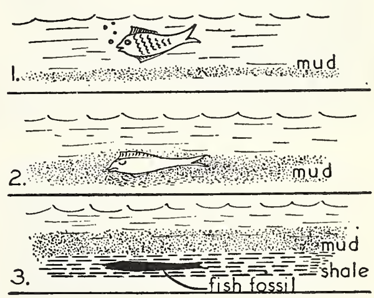

Fig. 3–7. The formation of a fossil. When the mud hardens into shale, the preserved remains of the fish become part of the rock.

in these waters die, fall into the accumulating sands and clays, and are buried. The fleshy parts of the animals decay, but the hard parts may remain as *fossils* when the sediments turn to rock. The shells of clams, mussels, and snails are frequently found as actual remains inside layers of sandstone and shale. Sometimes the shells themselves

disappear, but leave impressions that can be seen when the rock layers are split open. Fish skeletons also form fossils, and plant remains or impressions are often found in the rocks derived from swamp sediments. *Fossils are the remains or impressions of plants or animals preserved in rock.*

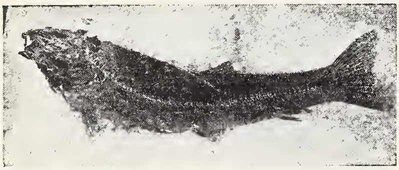

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Fig. 3–8a. A fossil fish in shale.

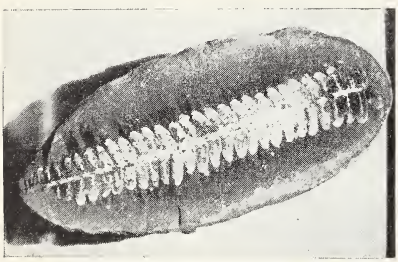

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Fig. 3–8b. A fossil fern in shale.

12. How organic sediments form. The two chief rocks formed from organic sediments are *limestone* and *coal.*

In the slightly deeper, clearer waters of the continental shelf just beyond the zone of clay deposition, great numbers of shellfish live. When they die, their shells accumulate just as other sediments do, layer upon layer, until they harden into limestones. At their shallow margins, these limestones may have a good deal of clay in them, but in deeper water they are likely to consist entirely of fossils. These limestones represent mineral matter that was dissolved out of rocks on land, carried to the ocean (or lakes) by rivers, and then extracted from the water by the shell animals of the sea. They consist chiefly of the mineral calcite, but differ in appearance according to the kinds of shells they contain.

Coquina, common in Florida, consists of shells recently and loosely cemented together. Fossil-bearing limestone is much older and more highly compressed than coquina, but its shells are large and easily visible. Compact limestone consists of microscopic shells tightly packed together, making it smooth and relatively hard. Chalk is similar to compact limestone, but it is much softer and smoother. Coral limestone is made of coral fragments naturally cemented together. All limestones bubble when tested with cold, dilute hydrochloric acid.

When ferns, mosses, twigs, and even tree trunks are buried in swamp waters and accumulate in great thicknesses, they undergo a slow decay by which they eventually lose almost all of their elements except carbon. At first they decay into *peat,* a brownish mass of mosses, leaves, and twigs. Peat burns well when dry. With further decay and with compression under other sediments, peat is converted into a harder and more com-

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Fig. 3–9. A sample of fossiliferous limestone in which individual shells can be seen.

pact material called *lignite,* or brown coal. Further change produces *bituminous,* or soft, coal. The entire transformation may take many thousands of years. It is estimated that a pile of peat 20 feet high is required to form a bed of bituminous coal 1 foot thick. Some sand or clay may mix with the accumulating plants to account for more or less ash or clinker when the coal is burned. Large deposits of sand and clay form the layers of sandstone and shale in which coal beds are usually found.

13. How chemical sediments form. Chemical sediments are formed when minerals dissolved in sea, lake, swamp, or underground waters are precipitated (thrown down) from the water by evaporation or chemical action. There are many chemical sediments. Two of the most important are rock salt and gypsum. Others will be described in the chapter on underground water.

Rock salt is the natural form in which our common table salt (sodium chloride) occurs as a sedimentary rock in thick layers or beds in many parts of the world. It consists almost entirely of the mineral halite, forming white or colorless cube-shaped crystals with three cleavages and a hardness of 2.5.

Gypsum (calcium sulfate and water) is colorless, white, or pink. It is number 2 in the scale of hardness. When heated, it loses water and crumbles into plaster of Paris. Like salt, it occurs in sedimentary layers and veins.

Both rock salt and gypsum are believed to have been formed by the continuous evaporation of the waters of salt lakes or ocean lagoons (shallow marine lakes behind sand bars).

14. Origin of metamorphic rocks. When bedrock in the earth's crust is subjected to greatly increased pressure, very high temperatures, or chemical action within the earth, it may change in many respects while still remaining in the form of solid bedrock. In its new form it is called metamorphic (*meta,* change; *morph,* form) rock. The pressure may come through large movements of the earth's crust which crumple and fold the bedrock. The heat may come from the intrusion of hot magma or from the friction of moving rock layers. The chemicals may come from magmas. These are but a few of the possible sources of pressure, heat, and chemical action that cause *metamorphism* (met uh *mor* fiz'm).

Increased pressure may transform the old rocks into rocks that are harder and less porous. The new rocks lack the appearance of stratification that they formerly had. In some rocks there is a rearrangement of the mineral grains into parallel bands that resemble the stratification of sedimentary rocks. Pressure may also tilt the layers of old sedimentary rocks or crumple them into folded mountainous formations. Increased temperature may melt the rocks so that when they re-harden they are

U.S. Geological Survey

Fig. 3–10. A coal bed. The dark horizontal layer running through the middle of the cliff is a seam of coal 8 feet thick. Above and below are layers of other sedimentary rocks.

W. A. Bell, Geological Survey of Canada

Fig. 3–11. Metamorphic rocks formed by the folding of sedimentary rocks in the Sutton Range, Quebec.

crystallized, as igneous rocks are. Chemical action may form minerals that did not exist in the old rocks. The fossils of sedimentary rocks are completely destroyed by metamorphism.

When metamorphism of bedrock takes place over a very large area, it is called *regional metamorphism,* and is usually caused by movement of the earth's crust. When it affects only a small area, it is called *local metamorphism.* Local metamorphism commonly occurs where hot magma is in contact with other rock.

15. Important metamorphic rocks. *Quartzite* is formed from sandstone. It is massive, hard, crystalline, nonporous, and composed almost entirely of quartz. It is one of the most durable of all rocks.

Marble is formed from limestone. Like limestone, it is composed chiefly of the mineral calcite. It responds to the acid test. It differs from limestone in being massive, harder, and highly crystalline. Pure marble is white. When impurities such as carbon, limonite, and hematite are present, they add attractive colors to the rock. Polished marble is one of the most beautiful and valuable of all building stones.

Anthracite coal is formed from bituminous coal. It is much harder, shinier, and splits with a shell-like fracture. Anthracite is usually found in *folded* mountain regions, whereas bituminous is found in regions of *horizontal* stratified rock.

Gneiss (nice) occurs in many varieties, most of which are formed from igneous rocks. One of the most common varieties, derived from granite, is called granite gneiss. It contains the same minerals—quartz and feldspar, with mica, hornblende or others—but the round grains of granite have been *foliated* or crushed into coarse parallel bands of alternating light and dark minerals.

Schist (shist), like gneiss, occurs in many varieties and is formed from many igneous and sedimentary rocks, but most commonly from shale. Schist may contain a variety of minerals, including two or more of such minerals as quartz, feldspar, mica, hornblende, and talc. In schist, the minerals are flattened out into such thin sheets or flakes that the rock spilts easily and is said to be *highly foliated.* Schists are named for their principal mineral, as in mica schist, talc schist, or hornblende schist.

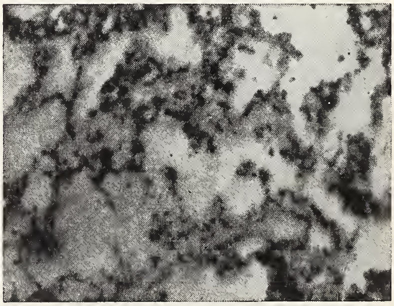

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Fig. 3–12. A specimen of polished marble from Pittsford, Vermont. Marble is metamorphosed limestone.

Slate is also formed from shale. Although the minerals in slate are too small to be seen with the naked eye, it contains tiny mica flakes which give it foliated structure like that in schist. Slate is much harder and smoother than shale, but splits easily at right angles to the direction of the pressure that turned the shale into slate. This kind of splitting is called *slaty cleavage.*

16. Summary of characteristics. It is worth while comparing the three classes of rocks with respect to a few outstanding characteristics. The sedimentary rocks are almost always *stratified* (although this may not show in a small specimen), are usually dull or noncrystalline in appearance, and they may contain fossils. The *igneous* rocks are almost always *unstratified* or massive, are almost always crystalline or glassy, and are almost completely without fossils. The metamorphic rocks are either massive (quartzite, marble, anthracite) or foliated (gneiss, schist, slate) though they may still show the original sedimentary layers from which they were formed. They are almost always crystalline, and they never contain fossils.

HAVE YOU LEARNED THESE?

Meanings of: stratified, unstratified, igneous, sedimentary, metamorphic, magma, lava, extrusive, intrusive, fossil

Diagrams of: rock symbols shown in Figure 3–6

Explanations of: how size of crystal is determined in igneous rock; the three groups of sedimentary rocks; how sediment forms rock; how rocks become stratified; fossils; origin of limestone, coal, rock salt, gypsum, metamorphic rocks

Classification of: the rocks listed in this chapter as igneous, sedimentary, or metamorphic

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) What are stratified rocks? What makes the strata different? (*b*) How do massive rocks differ in appearance from stratified rocks?

2. Define the three classes of rocks according to origin. Give examples.

3. Define magma. Explain what extrusive and intrusive rocks are.

4. (*a*) Explain what determines the size of crystals in an igneous rock. Give examples. (*b*) Explain, with examples, the different kinds of textures in igneous rocks, and the reasons for them.

5. Give brief descriptions of obsidian and one other extrusive rock. Do the same for granite and one other intrusive rock.

6. Explain the basis on which the sedimentary rocks are divided into three groups. Name them.

7. How do rock fragments turn to rock?

8. Explain how rock sediments become assorted when deposited in water. Name the rocks formed.

9. Describe conglomerate, sandstone, and shale.

10. Explain how sedimentary rocks become stratified. Draw the symbols used to show the various sedimentary rocks.

11. Explain how a fossil forms in a sedimentary rock.

12. (*a*) Explain the origin of limestone. Describe a few varieties of limestone. (*b*) Describe the formation of coal.

13. (*a*) Explain what chemical sediments are. (*b*) Describe the origin and characteristics of rock salt and gypsum.

14. (*a*) How does metamorphic rock form? (*b*) In what respects do metamorphic rocks differ from the rocks they are derived from? (*c*) Distinguish between regional and local metamorphism.

15. (*a*) Make a list of six metamorphic rocks and the rocks from which each one

originates. (*b*) Describe one or more massive metamorphic rocks. (*c*) Describe one or more foliated metamorphic rocks.

16. Compare igneous, sedimentary, and metamorphic rocks as to structure, crystallinity, and fossil content.

GENERAL QUESTIONS

1. Compare the origin of Mount Waddington, B.C. (made of granite), and one of the Monteregian Hills.

2. Why is obsidian considered to be a rock rather than a mineral?

3. Why are fossils comparatively rare in conglomerate?

4. How can white marble be distinguished from white quartzite? Give several ways.

5. Can fossils ever be formed in igneous rocks? Explain.

6. In what respects may the sediments carried by a river in summer and winter differ? Why?

7. How can footprints become fossils?

8. In what kind of climate was rock salt probably formed? Why?

STUDENT ACTIVITIES

1. Making collections of rocks and classifying them under the headings given in this chapter

2. Collecting fossils

3. Making collections of photographs illustrating rocks, rock structures, and fossils

4. Making a display of rock sediments and the rocks derived from them

5. Obtaining information about the origin and appearance of the rocks in which the following minerals are found: Asbestos in the Thetford district, Que., Gypsum on Cape Breton Island, Rock salt in southwestern Ontario, Coal in the Crows Nest Pass, Copper at Noranda, Que., Iron ore at Steep Rock, Ont.

SUPPLEMENTARY TOPICS

1. Other Chemical Sediments

2. The Origin of Coal

3. The Origin of Graphite

4. The Distribution of Igneous, Sedimentary, and Metamorphic Rocks in Canada.

5. The Formation of Fossils

6. Economic Uses of Rock

7. Pegmatites and Porphyries

See list of suggestions for further reading at the end of Chapter 2.

Chapter 4

READING TOPOGRAPHIC MAPS

1. Introduction. In addition to reading about land forms in textbooks, they may be studied through field trips, photographs, and topographic maps. Topographic (top uh *graf* ik) maps make it possible to study places that are too distant and too expensive to be visited in field trips, and they are far superior to photographs in providing accurate information. Topographic or contour maps may be defined as maps that show the relief and physical features of a region by the use of appropriate symbols. The physical features include plains, plateaus, mountains, hills, valleys, rivers, lakes, swamps, and many other land forms. Relief, the "ups and downs" of the earth's surface, is the difference in height between the highest and lowest points in a given area.

2. Mapmakers have their problems. The making of a map is a complex problem. *A map is defined as the representation of all or part of the earth's surface on a plane* (a flat surface such as a sheet of paper). Since the earth is a sphere, its surface is like the skin of an orange or the cover of a basketball, but vastly larger. Making a map of half the earth, for example, is like trying to make the skin of half an orange coincide with the flat surface of a table. It cannot be done, unless the orange skin is torn or stretched out of shape. Making a single map of the whole earth is even more difficult and requires more tearing or stretching. On the other hand, if a small section of an orange skin is taken, it can be flattened with less tearing or stretching. In other words, *the smaller the area mapped, the less distortion required.* But regardless of how small a section of the earth's surface is to be mapped, it is still part of a sphere, and therefore it can never coincide perfectly with a flat surface. There is no such thing as a perfect map, even for small areas.

3. How the different map projections are used. Mapmakers have suggested many schemes for showing the curved earth on a flat surface. Such schemes are called map projections. Each projection has its advantages and its disadvantages. The ideal map shows shapes, distances, and directions correctly, but no projection can do all of these things. Some projections show true shapes while distorting distances and directions. Some may show true directions, but distort shapes and distances. Still others may show both shapes and distances correctly, but only by using a series of disconnected map sections, as one might do with an orange-skin peeled into quarters. However, as stated above,

maps of small areas can be made with very little distortion in any respect.

There are many useful map projections, but only four will be mentioned here. The *Mercator projection* is an old and still valuable scheme that shows the whole world (except the extreme polar regions) on one single continuous map. It is indispensable to the navigator because *it shows true directions by straight lines.* The captain who wishes to sail from Halifax to Cherbourg draws a straight line on his Mercator chart between the two cities. The direction shown by this line, followed all the way from Halifax, will take him straight to his destination. The chief fault of the Mercator projection is its tremendous exaggeration of distances in high latitudes.

On the *gnomonic* (noh *mon* ik) *projection,* a straight line between two points shows the shortest route (great-circle route; see Chapter 21) between those points on the earth's curved surface. It is used in planning long voyages or flights, but since its directions and distances are distorted, other maps must be used to supplement it.

The Lambert conformal conic projection is used in making air navigation charts. For short flights, it shows true distances and great circle routes by straight lines, but adjustments must be made for true directions.

For small areas, the *polyconic projection* is nearly correct in all respects. It is used for the smaller scale maps in the National Topographic Series. The larger scale maps use a special form of Mercator's projection.

4. Which way is north? On any map, directions are shown by parallels and meridians. Parallels are circles that run around the world in an east-west direction parallel to the Equator. Meridians are half-circles that run in a north-south

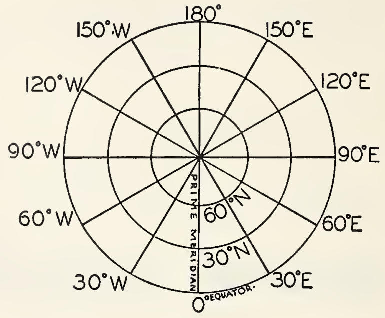

Fig. 4–1. A polar projection of the Northern Hemisphere. The North Pole is the point at the center of the map, and the Equator is the outer circle.

direction from the North Pole to the South Pole. (See Chapter 21 for a fuller explanation.) North or south on a map is obtained simply by finding and following any meridian; east or west is obtained by following any parallel. Most of us are accustomed to maps in which north is at the top, south at the bottom, east to the right, and west to the left. But in many projections this arrangement does not hold true. In polar-view maps (see Figure 4–1), north is toward the center, while east and west are merely opposite directions around the parallel circles.

5. How can places be located on a map? The location of places on the surface of the earth is shown on maps by means of latitude and longitude. Latitude is distance in degrees north or south of the Equator and is measured on parallels. Longitude is distance in degrees east or west of the prime meridian and is measured on meridians. In locating a place, we give its latitude in degrees north or south of the Equator and its longitude in degrees east or west of the prime meridian. No matter what projection scheme is used or what distortions a map has, all maps must show

the same latitude and longitude for any particular point on the earth's surface.

6. What the scale means. The scale of a map tells how the map compares in size with the piece of the earth's surface that it represents. With many world maps, as with the Mercator projection, the distortion of distance varies so much over the map that no single scale can be given. Small-area maps, such as topographic maps, present no such problem, however.

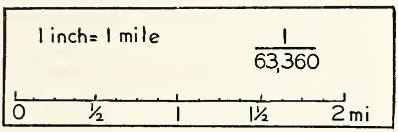

Fig. 4–2. Three ways of showing a map scale of 1 inch to a mile.

A *map scale is usually defined as the ratio of distance on the map to distance on the earth.* This ratio may be shown on the map in three different ways:

(1) *Verbally,* as a simple statement, such as "1 inch to 100 miles."

(2) *Graphically,* by a line divided into equal parts, and marked in miles or other units of length.

(3) *Numerically,* usually by writing a fraction to show what part of the *true* distances the *map* distances really are. The fraction is known as the R.F. or representation fraction. For example, the scale $\frac{1}{1{,}000{,}000}$ (also written 1:1,000,000) means that any distance on the map is one-millionth of its true length on the earth. This may also be expressed by saying that 1 *unit* of length on the map (1 inch, 1 centimeter, 1 foot, etc.) represents 1,000,000 of the *same units* on the earth.

Maps are always much smaller than the pieces of land they represent. The more closely the map approaches the land in size, the larger its scale is said to be. A map of Canada on an 8 inch by 10 inch sheet of paper, would have to use a very small scale, such as 1 inch (of paper) to 360 miles (of earth). On the other hand, a large wall map of the same area would use a *larger scale,* such as 6 inches (of paper) to 360 miles (of earth), usually expressed as 1 inch to 60 miles. A still larger scale such as 1 inch to 1 mile would require a sheet of paper nearly 100 yards long and almost as wide.

7. Showing elevation. In order to show land forms, maps must show the relief or the changes in height of the earth's surface. This can be done in many ways such as by shading, coloring, or even miniature sketching of land forms. The simplest and most accurate method for large-scale maps, however, is by the use of contour lines. Contour lines give exact elevations (heights above sea level) and show the shape of the land at the same time. They can be explained best by an illustration. Figure 4–3*a* is a sketch of an island in the sea. This island is 6 miles long, 3 miles wide, oval-shaped, and 113 feet high at its highest point. In an ordinary map the island would look as shown in Figure 4–3*b*. Such a map gives little information about the island. The shoreline shows the shape of the island *at sea level* and the scale indicates the length and width of the island, but the map gives no information about the height of the island, the steepness of its surface, or its shape above sea level. The mapmaker surveys the island and proceeds to turn this map into a contour map. On the map he locates a series of points shown by his survey to be 25 feet above sea level (Figure 4–3*c*). He joins these points with a *contour line, a line drawn through points at the same height above sea level.* Every point on this line is 25 feet higher than the shoreline. The

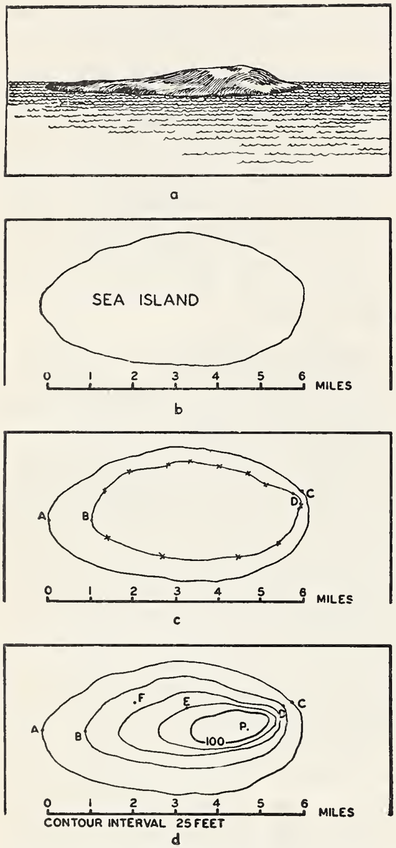

Fig. 4–3. The representation of an island by a contour map: (*a*) Sketch of "Sea Island" seen from a distance; (*b*) Ordinary map of "Sea Island"; (*c*) Map *b* with a 25-foot contour line added; (*d*) Contour map of "Sea Island."

shoreline is also a contour line, since it joins points all of which are at sea level (zero feet above sea level).

The distance along the ground between any two points is still found by use of the map scale! Using the scale in Figure 4–3*c*, we see that between *A* and *B* the island reached the 25-foot elevation in one mile, whereas between *C* and *D* the same height is reached in only one-fourth of a mile. Obviously, then, the island is steeper between C and D. Instead of figuring this out each time, we use the rule that *where contour lines are close together, the slope of the ground is comparatively steep; where contour lines are far apart, the slope of the ground is comparatively gentle.*

Now the mapmaker draws three additional contour lines showing where the island reaches the 50-foot, 75-foot, and 100-foot elevations respectively (Figure 4–3*d*). He is using a 25-foot *contour interval*, which is the *difference in elevation between two consecutive contour lines.* (Do not confuse the contour interval, which is difference in height, with distance along the ground. The horizontal distance between two points on consecutive contour lines is measured, as before, with the map scale.) If the land to be mapped is high and steep, the mapmaker will use a large contour interval such as 50 feet or 100 feet; if it slopes gently or is nearly level, the mapmaker will use a small contour interval such as 10 feet, 5 feet, or even 1 foot. For moderately rough land, a 25-foot contour interval is used.

To make the reading of contour lines easier, every fourth line is made heavier and its elevation is marked on it. The other contour lines are not numbered, but the contour interval is stated at the bottom of the map (see Figure 4–3*d*). Notice that the contour lines show three things: (1) elevation of the land; (2) steepness or gentleness of its slopes; (3) shape of the land at various heights.

8. National Topographic Series. The Surveys and Mapping Branch of the Department of Mines and Technical Surveys, and the Army Survey Establishment of the Department of National Defence, are responsible for the topo-

graphic mapping of Canada. The entire country has been mapped on a small scale (1 inch to 8 miles), and contoured maps are available on larger scales for much of the settled southern area. The standard large scale was 1 inch to 1 mile until 1950. In that year a new scale of $\frac{1}{50{,}000}$ (approximately 1.25 inches to 1 mile) was adopted. Each map area covers one-quarter degree of latitude from north to south, and one-half degree of longitude from east to west (roughly 18 miles by 23 miles in southern Canada). Each map area is named from a prominent part of the map, and is also given a reference number. The map area is published as two separate sheets, an eastern half and a western half. Lunenburg N.S. for example appears on sheet Lunenburg, west half, which is numbered 21 A/8,-W½. Other maps are published on scales of 1 inch to 2 miles, $\frac{1}{250{,}000}$, and $\frac{1}{1{,}000{,}000}$. The contour interval used most frequently in the east is 25 feet, and 25 or 100 feet in the west.

The various features of the contour map are shown in three colours. Contour lines are always printed in brown. Roads, railroads, and other works of man are printed in black, while water features such as rivers and lakes, are shown in blue. A complete key to the map symbols is found around the edge of the sheet.

9. Reading the contour map. *Direction.* As explained in Topic 4, directions are found by following meridians and parallels. If the map shows no meridans or parallels, it may have an arrow pointing to true north. Otherwise it can be assumed that north is at the top of the map.

Distance. In measuring distances, the scale of the map is first determined. If the scale is known in miles per inch, distances on the map may be measured with a ruler and converted into miles. With the new scale of $\frac{1}{50{,}000}$ adopted in 1950 this is difficult, and it is easier to use the graphic scale. When a graphic scale is printed on the map, the distance between two points can be marked off with any straight edge, such as the edge of a sheet of paper, or with a piece of string, and then held directly against the scale for reading. Zigzag distances along roads, rivers, etc., may be marked off in succession on a sheet of paper before measuring against the graphic scale.

Elevation. When a point is *on* a contour line, its *exact* elevation is known. For example in Figure 4–3*d*, point *B* is exactly 25 feet above sea level, and point *E* is exactly 75 feet above sea level. When a point is between two contour lines, its elevation is known to be *between* the elevations of the two lines. For example, point *F* is halfway between the 25-foot and 50-foot contour lines, so its elevation is approximately 37 feet. When the exact elevation of a hilltop is known, it is printed in the space at the top of the hill. Otherwise its elevation is estimated as more than that of the last contour line, but less than the elevation that the next contour line would have. For example, the elevation of point *P* is above 100 feet but under 125 feet. *P* may be anything from 101 feet to 124 feet.

Unless it includes the sea coast, a contour map is not likely to start from sea level. It must be remembered that each elevation given is *height above sea level,* not height above the lowest point on the particular map. To determine the elevation of any point, one should

start from the marked contour line that is nearest to it. For example, to determine the height of point Q (Figure 4–4) we begin from the marked 1000-foot contour line and count *up* in 25-foot "rises," since the contour interval of the map is 25 feet. Point Q is therefore 1050 feet above sea level. (We count *up* rather than *down* because we are approaching the top of the ridge.)

Determining the contour interval. When the contour interval is not given, it can be determined by noting the *difference in elevation* between any two marked contour lines, and dividing by the number of "rises" between them. For example, in Figure 4–4 the difference between two consecutive marked lines is 100 feet, reached in 4 "rises." Dividing 100 feet by 4 gives a 25-foot contour interval.

10. Land forms on contour maps. *Level land.* If a large part of a contour map shows no contour lines, it means that the rise or fall of the land in that area is less than the contour interval, and the land is therefore comparatively level. In Figure 4–4, for example, Grassy Terrace (in the southeast) has no contour lines on it and must be fairly level.

Cliffs. Where contour lines run very close together, the land is very steep. If contour lines coincide, it means that the higher ground is directly above the lower ground, and the contour lines therefore indicate a cliff. An example of this is shown at Sheer Cliff.

Hilltops. Closed circles or ovals at the end of a rising series of contours show the tops of hills or mountains, as at *J, K, L, M, and N* (Figure 4–4).

Ridges. Hills or mountains that are

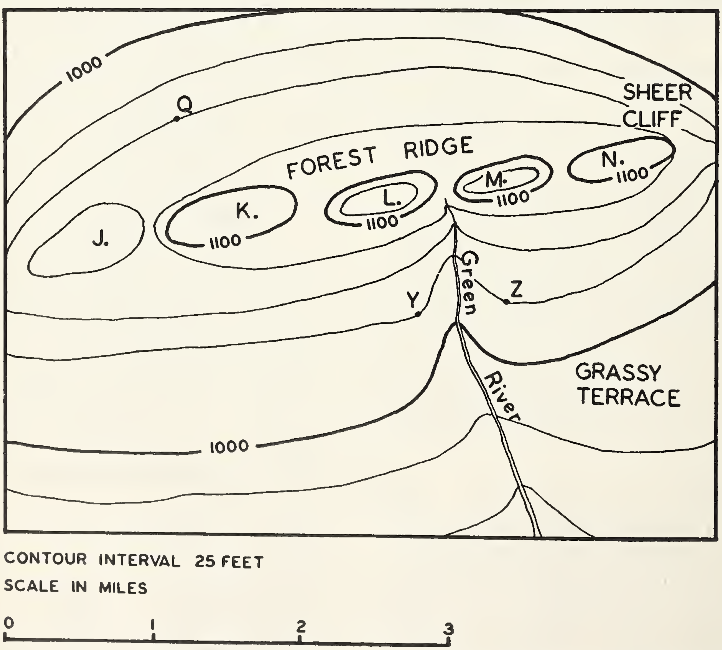

Fig. 4–4. Contour lines are far apart in level areas (Grassy Terrace) and close together at steep slopes. At a cliff they run together (Sheer Cliff). Circular or oval contours show hills. Long narrow oval contours show ridges.

comparatively long and narrow and may include a number of peaks are called ridges. They are shown by long oval contour lines, as at Forest Ridge.

River valleys. Where a river has cut a valley through the land, contour lines plainly show the carved-out valley. As each contour line approaches the valley, it can stay at the elevation it represents *only by bending* in the direction of the high land from which the river is running down (see Figure 4–5). On the map, then, *contour lines bend upstream where they cross river valleys.* This rule may be used to determine the direction in which a river flows. The direction of river flow can also be determined by noticing the elevations of marked contour lines. Common sense tells us, of course, that a river must flow from higher to lower elevations.

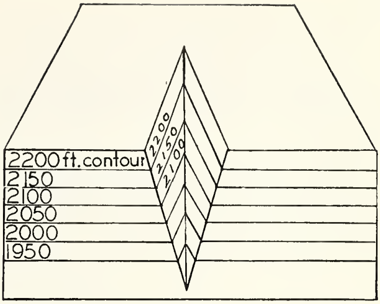

Fig. 4–5. Contour lines must bend upstream where they cross a river valley in order to stay at the heights they represent.

The *steepness of a river* is shown by the closeness of the contour lines that cross it. The *width of the valley* is approximately shown by the distance between the bent portions of each contour line, as between points Y and Z in the Green River Valley (Figure 4–4).

HAVE YOU LEARNED THESE?

Meanings of: map, topographic map, map scale, contour line, contour interval, relief

How to: read and use map scales; determine directions on a map; determine elevations on contour maps; locate hilltops, valleys, cliffs, steep slopes, gentle slopes, level land; determine the direction of river flow; determine the contour interval from the map

Explanations of: map distortion; large and small scales; use of large and small contour intervals

Descriptions of: the four map projections

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. What are topographic maps? Of what use are they in earth science?

2. What is a map? Why is mapmaking a problem? Why can a map of a small area be made with less distortion than a map of a large area?

3. What is a map projection? What three features do all maps show? Name four map projections, and describe the feature that makes each one useful.

4. How are north, south, east, and west found on any map?

5. How do maps show the location of places on the earth's surface?

6. (*a*) Define or explain what a map scale is? (*b*) Why is it impossible for many maps to have a single scale? (*c*) Describe the three ways of expressing a map scale. Give examples. (*d*) Distinguish between a large-scale map and a small-scale map.

7. (*a*) What is a contour line? How are contour lines drawn on maps? (*b*) How does a contour map show whether a slope is gentle or steep? (*c*) Define contour interval. Give examples of large and small contour intervals and their uses. (*d*) Distinguish between the use of the contour interval and the scale. (*e*) How are

contour lines drawn on maps to make it easier to read them?

8. Describe the following features of a Canadian 1:50,000 topographic sheet: area, scale, contour interval, colour scheme.

9. (*a*) How is direction found on a contour map? (*b*) How is distance measured on a contour map? (*c*) How is the elevation of a point determined on a contour map? Of a hilltop? When the map does not show sea level? (*d*) How can the contour interval be found when the map does not state it?

10. How does a contour map show: (*a*) level areas, (*b*) cliffs, (*c*) hilltops, (*d*) ridges (explain), (*e*) river valleys, (*f*) the steepness of a river, (*g*) the width of a valley?

GENERAL QUESTIONS

1. After plotting a great-circle route on a gnomonic projection, the navigator must transfer it to the Mercator projection. Why?

2. Globes are true representations of the earth's surface. Why aren't they used instead of maps?

3. Where are north, south, east, and west on a polar projection of the Southern Hemisphere?

4. Prove that the scale 1:50,000 is nearly the same as 1.25 inches to 1 mile.

5. Draw graphic scales for: (*a*) 1:50,000; (*b*) 1:250,000; (*c*) 1:1,000,000; (*d*) 1:62,500 (a common U.S. scale).

6. Express the above scales in words.

7. Answer the following questions about Figure 4–4: (*a*) What is the maximum elevation of each of the hilltops *J*, *K*, *L*, *M*, and *N*? How high is point *S*? *Y*? *Z*? (*b*) How high a cliff is Sheer Cliff? (*c*) From *L*, in what direction is *J*? *N*? *Q*? *Y*? (*d*) In which direction does Green River flow? (*e*) How far is it from *Q* to *Y*? from *J* to Sheer Cliff? (*f*) How wide is the Green River Valley? (*g*) How much higher than *J* is *L*? (*h*) At what elevation does Green River start? (*i*) How many feet does Green River drop in 1 mile, on the average?

8. Using a scale of 1 inch to 1 mile and a contour interval of 25 feet, draw a contour map of an island 6 miles long, 5 miles wide (north to south), steepest on the north side, and rising to a single peak 167 feet above sea level.

STUDENT ACTIVITIES

1. Reading topographic maps
2. Making models (of clay, plywood, cardboard, etc.) to illustrate contour map representation of slope, peaks, valleys
3. Drawing contour maps of imaginary or modeled land forms
4. Making scale maps of local streets, parks, etc.
5. Reading road maps for direction and distance

SUPPLEMENTARY TOPICS

1. The Making of Map Projections
2. The Making of a Topographic Map
3. Relief Maps
4. Showing Depressions by Contours

TOPOGRAPHIC SHEETS

The 1:50,000 National Topographic Series, and other maps, may be obtained from the Map Distribution Office, Department of Mines and Technical Surveys, Ottawa, Ont.

United States maps are obtainable from the Chief of Distribution, U.S. Geological Survey, Washington 25, D.C.

SUGGESTIONS FOR FURTHER READING

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World Maps and Globes, by Fisher and Miller. Essential Books, New York, 1944.

Chapter 5

ROCK WEATHERING AND GRAVITY

1. The origin of mantle rock. Mantle rock is the loose, broken-up rock material that covers a large part of the earth's crust. The earth did not always have this covering of mantle rock. When the earth was first formed by the cooling of molten material from the sun, its entire surface must have consisted of solid, unbroken, igneous rock. But the upper sections of this solid rock, immediately attacked by the destructional forces of weathering and erosion, have been broken off and worn into the loose earthy cover that now mantles the still unbroken bedrock.

2. Weathering and erosion. It is customary in earth science to classify destructional forces as either weathering or erosion. The distinction between these two destructional forces is usually made on the basis of whether or not the rock fragments that are formed by the destructional forces are also carried away by them. *Those forces that break rock into fragments but do not carry them away are listed under weathering.* Weathering derives its name from the fact that its principal agent is the atmosphere with its changing weather. But weathering also includes the work of plants and animals, for they too break up rock without carrying it off.

Those forces that not only break rock into fragments, but also carry away rock fragments, are listed under erosion. In order to carry rock fragments, these forces must be in motion themselves. The principal agents of erosion are winds (air in motion), waves, currents, rivers and all forms of running water, and glaciers (ice in motion). Weathering is ceaselessly at work over the entire land surface of the earth. Erosion attacks the rocks at fewer points, but more violently.

3. Residual or transported mantle rock? If the mantle rock formed by weathering remains in its place of origin, it is called *residual mantle rock.* It might be compared to a person who spends his whole life in one place. Mantle rock that has been carried from its place of origin to its present location is called *transported mantle rock,* and it is specifically named after the natural agent that carried it. Thus it may be known as *glacial* mantle rock, *alluvial* (river-carried) mantle rock, and so forth. Each of these forms of mantle rock will be described in the chapters that deal with their agents of erosion.

4. What are the types of weathering? The processes of weathering are classified as mechanical or chemical. *Mechanical weathering takes place when rock is cracked, split, or broken into*

smaller pieces of the same material, without changing its composition. The breaking of a granite cliff, for example, into boulders and pebbles of *granite* is mechanical weathering. *Chemical weathering takes place when rock, through the rotting away or decay of its minerals into different substances, crumbles apart.* The crumbling of black diabase rock into rusty brownish clay is an example of chemical weathering.

5. How mechanical weathering happens. Rocks are weathered mechanically by weather changes and by the movements of living plants and animals, as described under the following headings.

Effects of temperature change. Rocks warm up in the daytime and cool off at night. The resulting temperature changes are very large in mountain and desert areas, especially where the rocks are bare and exposed to the rays of the sun. Since the various minerals in a rock expand and contract at different rates, the effect of large temperature changes is to loosen the mineral grains and finally split them apart. Boulders, pebbles, and sand are formed by unequal expansion and contraction of the solid rock.

Frost action. Water expands by about 10 per cent of its volume when it freezes into ice. This expansion exerts a tremendous force on the walls of any container in which the water may be held, whether that container is a water pipe or a crevice in a rock. In climates where the temperature goes below freezing, and especially in porous rocks or rocks that are already cracked, the freezing of water may be the most damaging of all weathering processes. The more often the ice melts and then refreezes, the more often will this *frost action* be able to split the rock. The exposed bedrock of mountain tops is particularly subject to frost action. Above the tree line the surface may be entirely covered by large boulders in what are known as *boulder fields.* These are common in the Rocky Mountains, throughout Arctic Canada, the uplands of Newfoundland, the White Mountains of New Hampshire in the United States, and in many mountain regions. The effects of frost action can also be seen in the heaving and cracking of highway surfaces in winter.

Fig. 5–1. Boulder field formed by frost action high in the Big Horn Mountains of Wyoming.

U.S. Geological Survey

Fig. 5–2. A giant exfoliation dome shaped by the peeling of rock. Half Dome in Yosemite National Park, California. Note the climber standing at the base of the cliff, just above the rounded mass of rock at the bottom of the photo.

Exfoliation. The onion-like peeling of the outer layers of a rock is called exfoliation. It takes place chiefly in massive rocks like granite, which are uniform in composition.

Exfoliation is often explained as being due to the different rates of expansion and contraction of the outer and inner layers of rock. Because rock is a poor conductor, the outside layers are heated or cooled to a greater extent than the inner layers. The outside layers expand or contract together, whereas the movement of the inner layers is slight. The result is that the outside layers separate from the rest of the rock and peel off. This process takes place over and over. Most scientists believe that frost action and chemical processes are helpful in causing exfoliation to take place.

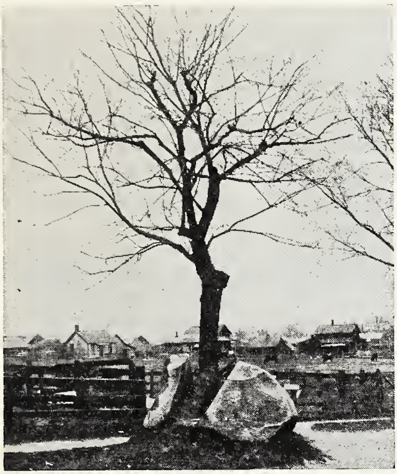
The effects of exfoliation on a small scale can be observed on many boulders. On a much larger scale, whole mountain tops of granite and other massive rocks weather by exfoliation, and great slabs of rock peel off to form rounded peaks known as *exfoliation domes.* Sugar Loaf Mountain, near Rio de Janeiro, the capital of Brazil, is a spectacular example of exfoliation. Numerous examples are found in areas of granite rock in central and southern Africa, southern India and Ceylon. In the United States there are a number of

U.S. Geological Survey

Fig. 5–3. Mosses and lichens growing on a rocky hillside can be seen as dark patches on the lighter-colored bedrock.

excellent examples in Yosemite National Park, California.

Action of plants. Numerous tiny plants such as the grayish lichens (*lye kens*) and the green mosses are found growing on rocks. Small as they are, these plants help to split and chip the rock surface. Trees and shrubs often grow through cracks in boulders that lie on top of soil. As tree trunks widen and their roots extend themselves, they exert powerful forces which enlarge the old cracks and form many new ones.



U.S. Forest Service

Fig. 5–4. A tree whose growth has split a boulder in two.

Action of animals. While animals do not attack rock directly, the burrowing animals contribute to weathering indirectly. Earthworms, ants, woodchucks, and other such animals dig holes in the mantle rock. These holes permit air and water to penetrate to the bedrock and weather it.

6. How chemical weathering happens. Chemical weathering of rock results from the action of chemical substances in the atmosphere and of chemicals produced by the decay of plants and animals. Moisture is needed for most chemical weathering processes, while heat speeds up their action. Consequently, chemical weathering is very active in hot, moist climates and much less active in dry climates. The major types of chemical weathering are oxidation, carbonation, hydration, solution, and acid action.

Oxidation is the union of oxygen with other elements. When moisture is present, the oxygen of the air unites rapidly with the iron in many rock minerals, making them rust and decay. Iron-containing minerals are usually black in color (examples are hornblende, biotite, and augite), and the iron rust that forms on them is easily seen.

Carbonation is the union of carbon dioxide with some of the compounds in rock minerals. Carbon dioxide gas, derived from either air or soil, dissolves in water to form a weak acid called carbonic acid (the same acid as in soda water). This acid attacks many minerals —foremost among which is the world's most abundant mineral, feldspar—and causes them to crumble into clay.

Hydration is the chemical union of water with some of the compounds in rock minerals. When water unites with minerals such as mica and feldspar, it causes them to puff up and eventually to crumble into clay-like materials.

Solution is the process by which rock minerals are dissolved in water. All minerals dissolve in water under proper conditions, but most rock minerals are only slightly soluble in the ordinary cold water of rain and the ground. Therefore any weathering by solution in ordinary water is insignificant. Salt and a few other minerals are very soluble in cold water, but they are unimportant as rock-making minerals. However, water containing carbon dioxide (carbonic acid) slowly dissolves calcite and gypsum,

these two minerals being the only rock-making minerals of importance that are affected in this way. The dissolving action of water hollows out the great underground caverns of the world from limestone bedrock, composed almost entirely of calcite.

Acids produced by the decay or wastes of plants and animals are dissolved by rain water and carried down through the mantle rock to the bedrock. Like carbonic acid, these acids dissolve some of the rock minerals and cause others to crumble. Their effects are considerable.

7. Which rocks are toughest? A very brief summary of the over-all effects of weathering on the principal rock-making minerals and their rocks is worth while at this point. Quartz, almost completely unaffected by water and acids, is practically immune to chemical weathering, and its hardness makes it extremely resistant to mechanical weathering as well. Crystals or masses of quartz weather very slowly into pebbles or sand grains. These pebbles or sand grains do not change chemically and are still pieces of quartz, usually white in color. Quartz is almost never worn down any finer than sand. Feldspar, hornblende, mica, augite, calcite, and gypsum are all subject to chemical weathering as well as to mechanical weathering. Mechanical weathering breaks them into pebbles and sands, but chemical weathering eventually decomposes these fragments into fine clays. Calcite and gypsum also disappear in solution, in which form they may be carried away by both surface and underground waters.

Most of the igneous rocks and many of the metamorphic rocks weather rapidly in moist climates, because they contain minerals that are attacked by oxygen and carbon dioxide in the presence of water. The first products of the weathering of these rocks are boulders, pebbles, sands, and clays, but in time even the boulders crumble to clay. Pebbles and sands will remain only if the rocks contain quartz or some other chemically resistant mineral.

Sandstones, quartzites, and quartz-pebble conglomerates are only as durable as the cements that hold them together. But when they break up, their quartz fragments remain as boulders, pebbles, and sands. Quartzites and well-cemented sandstones and conglomerates are among the most lasting of all rocks. Shales, weakest of the sedimentary rocks, split easily between layers and quickly disintegrate into the clays from which they were formed. Marbles and hard limestones are fairly resistant to mechanical weathering but their calcite undergoes slow attack by solution, making these rocks much less durable than quartzites or sandstones.

8. Weathering is a slow process. When learning about the weathering of such rocks as limestone or granite, one might get the impression that a building made of soluble limestone would wash away in the rain, or that a tombstone made of a quartz-feldspar-mica granite would crumble away to a mass of quartz pebbles and clay in a few years. But experience tells us that such is hardly the case. Under average conditions, weathering is a very slow process. It is estimated, for example, that even in moist climates the *rate of solution* of limestone exposed to the air is no more than one-fiftieth of an inch in a hundred years. Throughout the study of earth science, you should remember that most of the tremendous effects of natural processes come about after very long periods of time. The age of the earth is about 5000 million years. It would take 60 million years to dissolve a thousand-foot layer of limestone from the earth's surface. *At the same time,*

however, all the other weathering processes would account for the removal of far more rock.

9. Cleopatra's Needle. The rate at which weathering takes place depends upon many factors, chief of which are the kind and hardness of the rock, the agents acting on the rock, the climate, and the amount of protective cover on the bedrock. In general, weathering takes place most rapidly in weak rocks, in a moist climate with hot summers and cold winters, and where there is no mantle rock or vegetation to protect the bedrock from the atmosphere. Steep slopes and high altitude also favor rapid weathering.

An interesting illustration of the effect of climate on weathering is seen in the case of the obelisk (a stone monument) called Cleopatra's Needle. In 1880 it was taken from the dry, hot, Egyptian climate where it had stood almost unchanged for 3000 years, and was moved to the moist, hot-and-cold climate of Central Park in New York City. Chemical weathering and frost action attacked the granite in the obelisk to a greater degree than ever before, and hieroglyphics (inscriptions) on the obelisk suffered more damage in a few years than in as many centuries in Egypt. Now a waterproof coating is used to protect the obelisk from the weather.

New York City Department of Parks

Fig. 5–5. The obelisk Cleopatra's Needle, in Central Park, New York City.

10. Identifying residual mantle rock. When mantle rock that is formed by weathering stays in its place of origin, it can usually be recognized as residual mantle rock by certain general characteristics. Unlike transported mantle rock, which tends to end suddenly where the bedrock begins, residual mantle rock merges very gradually with the underlying bedrock from which it was weathered. It passes from fine soil into coarser but similar mantle rock, then into decayed bedrock, and finally into unweathered bedrock. Transported mantle rock

Fig. 5–6. Residual mantle rock is finest at the surface and becomes coarser with depth. Beneath it lies the bedrock from which it has been weathered.

may contain boulders and pebbles that are different from the bedrock, whereas all boulders or pebbles in residual mantle rock are similar to the underlying bedrock from which they were weathered.

11. When gravity moves rock. It has already been pointed out that mantle rock may be removed from its place of origin by the agents of erosion. While it is true that these agents—winds, waves, running water, and glaciers—get their motive power from the force of gravity, it is also true that gravity alone may cause mantle rock to move. Wherever the slope of a hill or mountain is sufficiently steep, rock fragments may fall or slide down. The movement of mantle rock by gravity alone may be described as follows.

Fig. 5–7. A talus slope formed from frost-shattered rock in northwest Canada.

Geographical Branch, Dept. of Mines & Technical Survey, Canada

Talus. When rocks weather at the top and face of very steep slopes or cliffs, the loose fragments tumble immediately to the foot of the incline. Here they pile up in an accumulation of mixed boulders, pebbles, sand, and clay to which is given the name *talus* (ankle). This mantle of talus hides the lower part of the slope and rests against it at an angle that is decidedly less than that of the cliff, but often as steep as 40 degrees. Talus slopes are a common sight wherever there are cliffs.

Landslides. Sudden movements of large quantities of mantle rock down steep hillsides or mountainsides are called *landslides.* (Similar movements of snow, or of snow and rock, are called avalanches.) These slopes are usually not so steep that weathered rock falls immediately, as it does from cliffs, but they are too steep for loose rock to remain after large quantities accumulate. Minor landslides occur frequently in temperate climates during early spring. This is how they happen. In winter, frost action on the hillsides splits apart many boulders and rock fragments, but they do not fall because the ice still holds them together. Then warm, rainy weather in spring melts the ice, and the added weight of the rain in the mantle rock often provides just the push needed to start the mass sliding. "Look out for fallen rock," a warning sign commonly seen on highways flanked by steep hillsides, suggests the frequency of such occurrences. Though common in the springtime, landslides may take place at any time of the year, especially after heavy rains. In earthquake regions, landslides may be touched off by earth tremors.

Hillside creep. On moist hillsides that are not steep enough for landslides,

W. H. Boyd, Geological Survey of Canada

Fig. 5–8. Turtle Mountain, Alberta. The scene of the famous landslide of 1903.

the top layers of mantle rock slip downhill so slowly that careful measurement through many years is required to show their movement. Such movement is called *hillside creep*.

12. Gravity aids weathering. Mantle rock that lies on top of bedrock provides the bedrock with partial protection against the atmosphere, thereby slowing down the rate at which the bedrock weathers. On steep slopes, however, gravity tends to remove mantle rock and thus keep the bedrock continually exposed. Gravity is therefore regarded as an aid to weathering, and its action is largely responsible for the fact that steep slopes weather more rapidly than gentle ones.

HAVE YOU LEARNED THESE?

Meanings of: weathering, erosion, chemical weathering, mechanical weathering, residual mantle rock, transported mantle rock, talus, exfoliation

Explanations of: the origin of mantle rock; the distinction between weathering and erosion; the distinction between mechanical and chemical weathering; the distinction between residual and transported mantle rock; the processes of mechanical and chemical weathering; the work of gravity; the weathering of specific rocks and minerals; the formation of exfoliation domes; the rate of weathering

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. Define mantle rock, and explain how it has originated.

2. Distinguish between weathering and erosion. Name the agents of each.

3. What is the difference between residual and transported mantle rock?

4. What distinction is there between chemical and mechanical weathering? Give examples.

5. (*a*) Explain how temperature changes and frost action weather rock mechanically. Which conditions are most

favorable to these processes? (*b*) Explain how plants and animals may bring about mechanical weathering of rock. (*c*) Describe and explain exfoliation and exfoliation domes.

6. (*a*) What substances cause chemical weathering? (*b*) In what type of climate is chemical weathering most active? Least active? Why? (*c*) Explain the weathering action of (1) oxidation, (2) carbonation, (3) hydration, (4) solution, (5) acids of plant and animal decay.

7. (*a*) Explain how weathering affects each of the principal rock minerals. (*b*) Explain how weathering affects the common rocks.

8. Discuss the length of time involved in weathering processes.

9. Discuss the factors that determine the rate of weathering.

10. How can residual mantle rock be distinguished from transported mantle rock?

11. (*a*) Explain how and where talus forms. (*b*) Explain how landslides occur. (*c*) Explain hillside creep.

12. How does gravity aid weathering?

GENERAL QUESTIONS

1. Why is frost action likely to damage sandstone more than limestone?

2. In what respects does the weathering of a bare mountain peak differ from the weathering of the bedrock under the soil of a forest?

3. Why do slates weather more slowly than shales?

4. Sandstones cemented by lime weather much more rapidly than those cemented by silica. Why?

5. What materials may be used to protect Cleopatra's Needle from the weather in New York City?

6. In parts of Bermuda where the limestone bedrock consists almost entirely of white calcite, with a small percentage of iron-containing minerals, the residual mantle rock is a fine red material. How is this explained?

7. What should be the content of residual mantle rock formed in a humid climate from a granite composed of quartz, feldspar, and black mica?

8. Why are the pavements of streets and highways damaged so much more in the winter months than in the summer months in most of Canada? (Compare the processes of weathering in the two seasons.)

STUDENT ACTIVITIES

1. Collecting, arranging, and studying samples of mantle rock materials to illustrate mechanical and chemical weathering

2. Collecting and studying samples of residual and transported soils

3. Making field trips to road cuts, building excavations, quarries, etc., where exposures of mantle rock can be seen and studied

4. Collecting photographs of features described in this chapter

5. Clipping articles from newspapers and magazines to illustrate such topics as landslides, etc.

6. Locating places in the neighborhood that illustrate specific types of weathering, mantle rock, and effects of gravity

SUPPLEMENTARY TOPICS

1. Famous Landslides of Recent Times
2. The Chemistry of Rock Weathering
3. Weathering in the Vicinity
4. Exfoliation Domes
5. Residual Soils
6. Talus Slopes

TOPOGRAPHIC SHEETS

1. *Landslides:* Frank, Alberta (shows the Turtle Mountain Landslide of 1903, scale 1 inch to 1 mile; obtainable from the Map Distribution Office, Ottawa)

2. *Exfoliation domes and cliff:* Yosemite Valley, California, obtainable from Chief of Distribution, U.S. Geological Survey, Washington 25, D.C.

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Chapter 6

UNDERGROUND WATER

1. Water in the earth. The presence of water in the upper portions of the earth's crust shows itself in many ways. Water may explode in the steaming eruptions of geysers, boil over in hot springs, pour from rock fissures over fantastically colored mineral terraces, or trickle steadily from hillside springs. Below the surface it may seep slowly through the mantle rock into swamps, lakes, rivers, and wells, or run mysteriously through deep underground caverns.

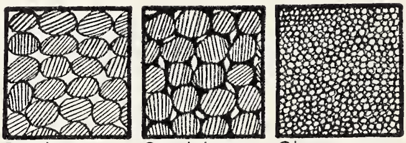


Fig. 6–1. The pores or spaces in sand, sandstone, and clay as seen through a microscope. Water passes easily through sand and sandstone, but not through clay.

2. Where underground water comes from. The water in the ground is derived almost entirely from the rain. Whenever rain or snow falls upon the earth's surface, some of it runs off into rivers, some returns quickly to the air by evaporation, and some enters the ground. The percentage that enters the ground depends upon many conditions —whether the ground is level or sloping; whether the surface is hard rock or mantle rock, absorbent or nonabsorbent; whether vegetation is present to slow down and absorb the water on the surface; whether the air is hot or cold, dry or humid.

3. Are rocks porous? All rocks have some pore space in them, but the amount of such space in solid rock varies from as little as 1 per cent in granite and other igneous rocks to as much as 30 per cent in some sandstones. Pumice that floats, of course, may be far more porous. In gravels, sands, and clays, pore space is usually high and may amount to as much as 50 per cent. The porosity of a particular mantle rock or bedrock determines how much water it can hold, and it is of great importance in the formation of springs and wells.

Materials that permit water to go through them easily are said to be *permeable* or *pervious;* those that do not are *impermeable* or *impervious.* Al-

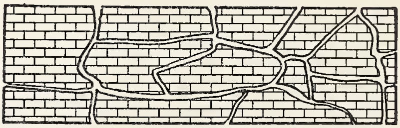


Fig. 6–2. Diagram of limestone beds showing fissures and cracks that permit water to pass through the limestone.

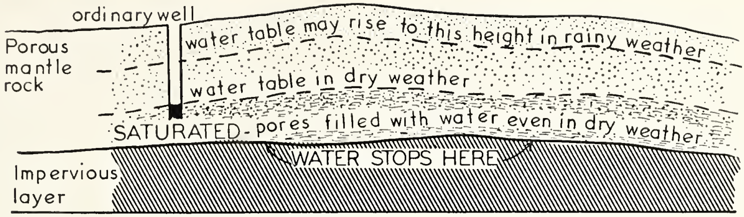


Fig. 6–3. Rain seeps down through porous mantle rock as far as an impervious layer, forming a water table. The water table rises in rainy weather and drops in dry weather.

though most porous materials are also pervious, there are some exceptions. In shale and clay, the pores are so tiny that it is almost impossible for water to pass through them, so these materials are impervious. In contrast, although limestone is nonporous rock, beds of limestone are often sufficiently cracked to allow water to pass through them.

4. Forming the water table. When rain falls on porous mantle rock, it seeps through the openings or pore spaces until it reaches an impervious material. The impervious material may be a layer of clay or any impervious bedrock such as shale or granite. Unable to penetrate the impervious rock, the water fills the pores at the bottom of the mantle rock layer. As the rain continues, more and more of the bottom mantle rock becomes *saturated* (its pore spaces are filled with water). The water in this saturated lower portion of the mantle rock is known as the *underground water* or *ground water*; the upper level of the saturated portion is called the *water table*. Above the water table, the mantle rock particles may be coated with thin films of water, but air fills most of the pore space (see Figure 6–3).

The depth of the water table below the surface varies from place to place with the thickness of the porous mantle rock, the slope, and the amount of rainfall. In desert regions there may never be enough rainfall to form a water table. The position of the water table also varies from day to day with the weather, rising when the weather is rainy and falling when the weather is dry. Between rains, water slowly escapes from the ground by evaporating into the air, by oozing into springs, swamps, and lakes, and through absorption by plants. In hilly country the water table is nearer to the surface in the valleys than in the higher land. Figure 6–4 shows the relation of the water table to the features of local topography in hilly country.

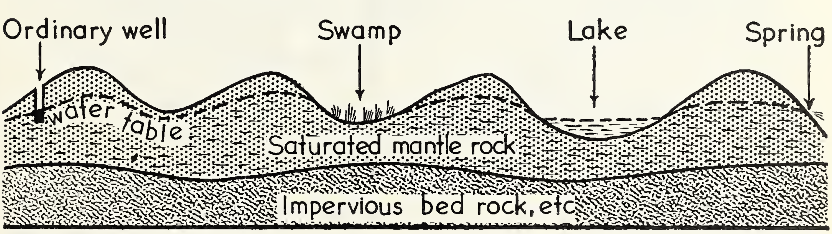


Fig. 6–4. In hilly regions the water table is usually far below the surface. In valleys the water table may rise above the surface to form lakes, swamps, and springs.

5. Ordinary wells and springs. Wherever the water table reaches the surface, the ground water oozes out. This rarely happens in level ground unless heavy rains have saturated the entire thickness of mantle rock, but it is quite likely to happen on hillsides. Here and there on hillsides where the water table cuts the surface, ground water may run into small natural basins called *hillside springs* (Figure 6–4). At camp sites, along hiking trails, and in farmland, it is common practice to drive a piece of narrow pipe horizontally into the hillside below the water table, in order to provide a path by which the ground water may come out in quantity. These, too, are called springs. Ground water is naturally filtered by the mantle rock through which it seeps and is usually perfectly clear. Dissolved substances, however, may be present in it, and its freedom from harmful materials depends on whether or not the ground through which it passes has been contaminated by human or animal wastes or poisonous minerals.

In places where the water table does not reach the surface, the ground water may be reached by digging or driving wells into the mantle rock (see Figure 6–3). If these wells are to provide water in all seasons, they must go considerably deeper than the lowest level to which the water table is likely to fall in dry weather. If the well is lined, its lining must be perforated to allow the ground water to seep in at either the bottom or the sides, or at both places. A well of this type, known as an ordinary well, contains water from its bottom up to the level of the water table. As the water table rises and falls with weather changes, so does the level of the water in the well. *Both the hillside spring and the ordinary well receive their water from the rains in their own vicinities.*

6. Artesian formations. Rain water may enter porous bedrock as well as porous mantle rock. In many parts of the world, beds of porous sandstone outcrop on hillsides and mountainsides,

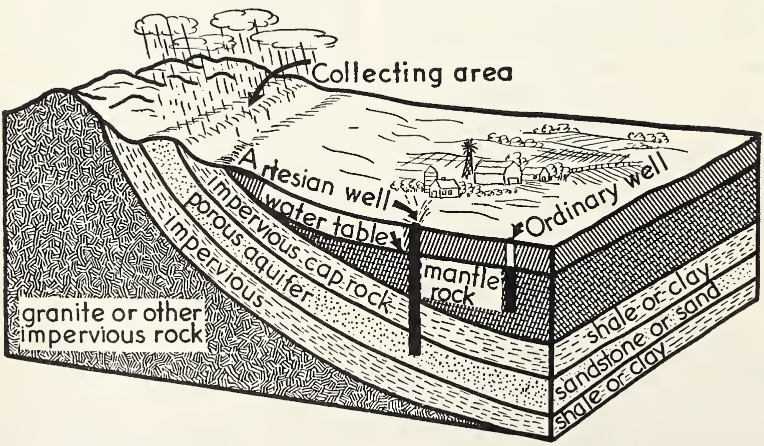


Fig. 6–5. The rain that enters the aquifer of an artesian formation is imprisoned between two impervious layers. For this reason, it may travel great distances underground before rising to the surface in an artesian well. Artesian water rises because of the pressure of the water behind it at higher levels.

then continue underground away from the mountains and between beds of impervious rock (see Figure 6–5). Rain water that enters the porous layer (known as the *aquifer* (*ak* wuh fer) or water-bearing layer) at its outcrop seeps slowly down through the pores of the rock, being prevented from escaping, either sidewards or downwards, by the impervious rock layers above and below. The top impervious layer, usually shale, is known as the *cap rock*. The entire formation, consisting of a porous layer outcropping between two impervious layers and sloping away from the mountain, is known as an *artesian* (ar *tee* zhun) *formation*.

Artesian formations may be very extensive. One such formation outcrops in a belt hundreds of miles long at the eastern base of the Rocky Mountains, and then dips eastward beneath the surface layers of the Great Plains in North Dakota, South Dakota, Nebraska, and Kansas, hundreds of miles away. Deep artesian wells are particularly important when they are found in arid areas. Artesian formations underly parts of the arid interior of Australia and the Sahara desert.

7. Artesian wells and springs. Rain and melting snows pour tremendous quantities of water into the aquifers of artesian formations where they outcrop in mountain regions. Like the water in a great sloping pipe, this water is under pressure. When wells are drilled into the aquifers, even hundreds of miles away from the outcrops, water rises in the wells and may spout into the air if the water pressure is sufficient. *Artesian wells* are wells, in which *the water comes from aquifers below an impervious layer* (see Figure 6–5). Unlike ordinary wells in the upper mantle rock, artesian wells do not obtain water from the local water table. Their water comes from distant outcrops, and they are therefore not dependent on local rainfall. This is particularly important for regions like the Great Plains whose rainfall is light and unreliable. Artesian wells can usually provide much larger quantities of water than ordinary wells, and their water is less likely to be contaminated.

Artesian wells vary greatly in depth. As a rule, the greater the distance from the outcrop, the deeper the aquifer. Queensland and New South Wales have the largest and deepest artesian basin in the world; wells hundreds of miles from the outcrops go down to 4000 and 5000 feet, and in one case 7000 feet to reach the aquifer. Other artesian basins are much shallower and as on Long Island, N.Y., the pressure in the wells is also less, and the water has to be pumped to the surface. (The water pressure in an artesian well depends on the difference in level between the well and the water in the outcrop.)

Artesian formations may be broken naturally by rock fissures through which artesian or fissure springs emerge without the need for drilling.

8. Oil wells and gas wells. Oil wells and natural gas wells often occur in sedimentary rock formations that greatly resemble artesian formations (see Figure 6–6). As in artesian formations, a layer of porous sand or sandstone lies between impervious beds, usually shale. Instead of being entirely saturated with water, part of the sand or sandstone is saturated with either petroleum oil, natural gas, or both. The water (usually salt water) is heaviest of the three materials, and is found in the lowest part of the saturated rock; above it is the oil; on top is the very light natural gas.

In the common type of occurrence shown in Figure 6–6 the rock layers are bent upward in a formation called an *anticline*, an *upfold of rock strata*. If

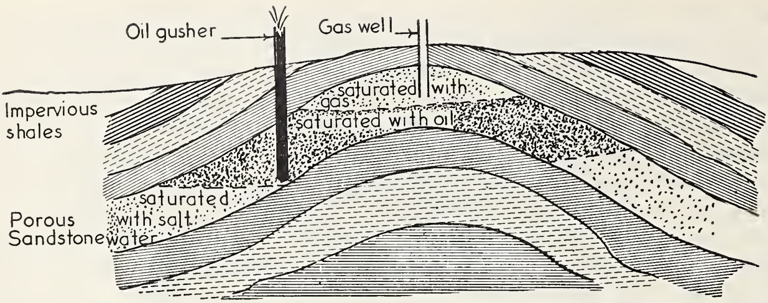


Figure 6–6. Cross section showing an oil well and a natural gas well in an anticlinal rock formation.

the gas pressure above or the water pressure below is sufficient, oil is forced out of the pores of the rock with enough force to make it spout out of the wall as a *gusher*. If pressure is not sufficient, the oil is pumped out. Natural gas is drawn out through pipes in which it may be transported for more than a thousand miles. The leading oil- and gas-producing province of Canada is Alberta, with smaller quantities from Saskatchewan, Manitoba, Ontario, and New Brunswick.

9. Why ground water is cool. Observations of temperatures within the earth show that at a depth of about 50 feet, protection from weather changes is so complete that the *mantle rock stays at the same temperature throughout the year*. The temperature at which it stays is the *average yearly temperature of its location*, which in most parts of southern Canada is somewhere between 32 and 50 degrees Fahrenheit. The water of an ordinary well or spring has practically the same temperature as the ground from which it comes. This explains why the water is comparatively cool in summer but never freezes in winter. Since spring or well water is close to the average temperature of its locality, such water is obviously colder in a cool climate like Quebec's than in a warm climate like Florida's. In northern Canada where the ground temperature is permanently below freezing point, there are no wells and few springs.

10. Warm springs, hot springs, and geysers. Below the 50-foot depth, heat from the earth's interior raises the earth temperatures at the rate of 1 degree Fahrenheit for every 50 to 75 feet, varying with the locality. Water from deep artesian wells or springs may therefore be considerably warmer than water from ordinary wells or springs. Fissure springs at very great depths may be warm enough to be called *warm springs* or even *hot springs*, as at Warm Springs, Georgia or Hot Springs, Arkansas. But ground waters may be hot without coming from great depths. In regions of comparatively recent volcanic activity, lava rock just a short distance below the surface is still hot enough to boil water. In such places the ground water may come to the surface as *hot springs* that are boiling or nearly so. Here and there in Yellowstone and other volcanic regions, hot springs emerge through sticky colored clays formed by the weathering of the volcanic rocks. These sputtering hot springs are called *paint pots* or *mud volcanoes*.

Boiling hot springs that erupt from time to time as gushers of hot water and

Geographical Branch, Dept. of Mines & Technical Survey, Canada

Fig. 6–7. Ground ice in the permafrost, Prince Patrick Island, Northwest Territories.

steam are called *geysers*. There are only a few parts of the world in which these scenic wonders occur, the most important being Yellowstone National Park in Wyoming, North Island in New Zealand, and Iceland. Old Faithful is not the largest geyser in Yellowstone, but it is famous for both its height and its regularity. It erupts about every 65 minutes and takes several minutes to propel more than a million gallons of water over 150 feet high.

Geyser eruption is like the explosion of a hot water boiler or pressure cooker. The "boiler" is a fissure or "geyser tube" which extends many feet down into the hot rock. At the bottom of this tube, ground water, under pressure of the water above it, is "superheated" to a temperature far above water's normal boiling point. As the heated water expands, it causes the water above it to overflow onto the surface. This relieves the pressure. The superheated water explodes into steam, blowing out the water above it in the form of a geyser eruption.

11. The minerals in ground water. Rain water is water that has been "naturally distilled" by the heat of the sun. Therefore it has no dissolved mineral matter in it. As ground water, however, its slow passage through the mantle rock or bedrock gives it ample opportunity to dissolve minerals. The kind and quantity of mineral matter which it contains depend largely on the kind of mantle rock or bedrock through which it passes, the distance it travels underground, and its temperature.

Dissolved minerals that contain the elements calcium, magnesium, or iron make water *hard*. Of these, calcium (from calcite) is the commonest cause of hardness. The dissolved minerals in hard water interfere greatly with its use.

Courtey Northern Pacific Railway

Fig. 6–8. Boiling water and steam erupting over 150 feet high from Old Faithful Geyser in Yellowstone National Park, Wyoming.

In laundering, they react with soap to form sticky curds instead of lather. In boiler tubes and hot-water pipes they form deposits of *boiler scale* which eventually clog the pipes and make expensive cleaning or replacement necessary.

Artesian water is usually harder than ordinary ground water, since it travels farther and may be warmer, enabling it to dissolve more mineral matter. Ordinary ground water is almost always harder than river water. In regions where limestone, with its high percentage of calcite, is found, practically all the water is hard.

12. Mineral springs. A spring whose water contains so much dissolved mineral that it cannot be used for ordinary drinking or washing purposes is called a *mineral spring.* The high mineral content of the water may be due to its passage through very soluble rock (such as salt beds in Nova Scotia), or to the fact that it contains large quantities of acid-forming gases such as carbon dioxide (example: Saratoga Springs, N.Y.) or hydrogen sulphide (example: Mansonville, Quebec), or to the fact that it is very hot (example: Hot Springs, Arkansas). Many mineral spring areas have become *spas* or health resorts. In desert regions, *alkali mineral springs* may be poisonous.

13. Destructional work of ground water. Although limestone is not a porous rock, limestone strata are frequently split by fissures that run down from the surface and by cracks that run horizontally between the beds. Ground water always contains carbonic acid, formed by dissolved carbon dioxide. As ground water runs through these cracks and fissures in limestone, its carbonic acid slowly dissolves and removes more and more of the limestone. After thousands of years, the fissures may grow into large, circular, surface openings, while the cracks between the beds form networks of irregular underground tunnels many miles in length and hundreds of feet high in places. The surface openings are called *sink holes* or *sinks,* and the tunnels are called *caverns* or *caves.* Sinks may also be formed by the collapse of small sections of caves. Water often collects in sink holes which are clogged at the bottom by broken rock, forming *sink-hole ponds.*

When a large section of a cave roof collapses and leaves a middle section standing, a *natural bridge* may be formed. More often, however, natural bridges in limestone regions are formed when a surface river disappears into a fissure in the bedrock, runs underground

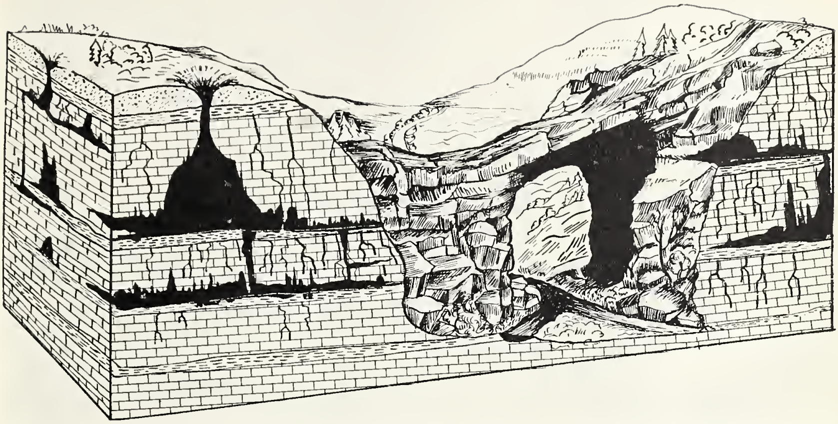


Fig. 6–9. Diagram showing the surface topography and underground structure of a limestone region of caverns, sink holes, and a natural bridge.

a short distance, and then gushes out on the face of a cliff. As the fissure is enlarged, the area between it and the cliff is left as a natural bridge. The famous Natural Bridge of Virginia is believed to have been formed in this manner.

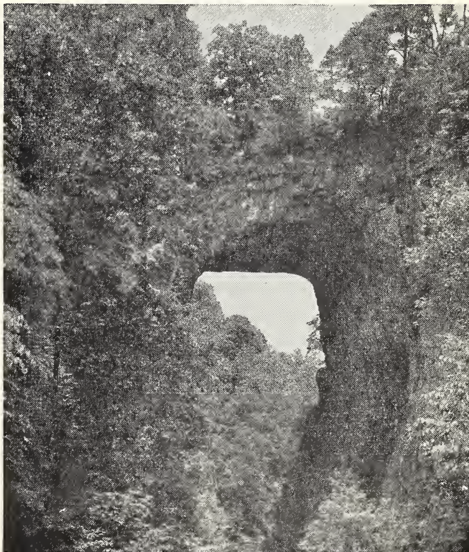
M. E. Wilson, Geological Survey of Canada

Fig. 6–10. A limestone surface eroded by solution along joints, near Kingston, Ontario.

Limestone is a common surface or near-surface bedrock, and limestone caverns occur in almost every part of the world. Some of the largest limestone caverns are found in Yugoslavia, south-central France, the West Indies, the Mammoth Cave area of Kentucky, and the Carlsbad Caverns of New Mexico. Although there are many small caverns in Canada, large ones are rare.

Fig. 6–11. The Natural Bridge of Virginia is a result of the destructional work of ground water in limestone bedrock. It is 90 feet long, 150 feet wide, and 215 feet high.

Courtesy Virginia State Chamber of Commerce



Courtesy Santa Fe Railway

Fig. 6–12. The great Dome Room of Carlsbad Caverns, where thousands of slender stalactites hang from the ceiling. A few stalactites have joined stalagmites to form columns. As in most caverns, the rock is limestone, composed of the mineral calcite.

Caverns may be formed by the action of ground water in other soluble rock beds such as gypsum or salt, but these materials are much less common than limestone. In regions of caverns, almost all of the rain water enters the ground through sink holes and fissures, and there are very few surface rivers. Caverns often form at several different levels, hundreds of feet down, particularly when insoluble layers such as shale alternate with the soluble limestones.

14. Mineral deposits by ground water. The minerals dissolved in ground water are deposited by it in a variety of ways. In places where ground water drips from the roof of a limestone cave, it very slowly deposits some of the calcite held in solution—partly because of evaporation, and partly because of decreased pressure and the escape of acid-forming gases like carbon dioxide. Deposits shaped like icicles are formed, and they hang down from the roof along the lines of the dripping water. These slender calcite formations are called *stalactites* (stuh *lak* tyte). At the same time, as each drop of water spatters on the floor below the stalactite, it deposits additional calcite which grows upward in the form of a blunt, rounded mass called a *stalagmite* (stuh *lag* myte). When stalactites and stalagmites meet, columns or pillars are formed.

Calcite deposits around mineral springs are called *travertine* (*trav* er tin). Among the most famous of such deposits are the delicately colored travertine terraces of the Mammoth Hot Springs in Yellowstone National Park (see Figure 6–13). Here the hot water pours out of long hillside fissures in limestone bedrock, depositing some of its dissolved calcite as it cools. Tiny plants, called algae (al jee), grow on the moist terraces, producing a variety of beautiful colors.

Around the openings of geysers, a white porous substance called *geyserite* is deposited, often accumulating in the shape of a cone. Geyserite consists of

Courtesy The Milwaukee Road

Fig. 6–13. Travertine deposits on Cleopatra Terrace of the Mammoth Hot Springs in Yellowstone National Park. The hot spring waters have destroyed all the vegetation on this part of the hillside.

silica (quartz), brought to the surface from the hot igneous rock through which the geyser waters pass.

Hot ground water often deposits minerals in cracks and fissures in bedrock, forming *veins* which may contain such minerals as quartz, calcite, gold, silver, and many others. *Petrified* wood is formed when the decaying wood of buried trees is slowly removed by ground water which leaves mineral matter in its place. The Petrified Forest of Arizona originated in this way.

15. Conserving ground water. Through springs and wells, ground water forms a direct source of water supply for millions of people in Canada, not only on farms, but in many large city areas as well. This is particularly so in southwestern Ontario and on the Prairies. Where many wells are drilled, more water is taken out of the ground than is replaced by precipitation, and the water level has dropped. This has happened in the coastal areas of New York State and New Jersey where not only is there a danger of water shortage, but also salt water from the nearby ocean seeps in and contaminates the wells.

An artesian formation underlies the Thames basin in England. Artesian wells are consequently used for industrial purposes and fountains in London. Too much water has however been taken from the basin and the water which once came to the surface under pressure, now has to be pumped up.

Measures that help to maintain ground water levels include the conservation of forests and other natural vegetation—for these absorb rain better than bare or cultivated ground—the damming up of small streams to give rain more time to soak into the ground, and careful regulation of the pumping and use of ground water.

HAVE YOU LEARNED THESE?

Meanings of: ground water, water table, stalactite, stalagmite, ordinary well, artesian well, travertine, geyserite

Explanations of: porosity, saturated, pervious, impervious, ordinary well, hillside spring, temperature of ground water, water hardness, artesian well, fissure spring, oil well, hot springs, geysers, mineral deposits, mineral springs, sink holes, caverns, natural bridges, geyser action, the problem of conserving ground water

Diagrams of: the water table and an ordinary well; artesian formations

Factors determining: depth of the water table; purity of ground water; minerals in ground water

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. Describe some of the ways in which the presence of water in the earth is shown.

2. What conditions determine how much rain enters the ground?

3. (*a*) Compare the various forms of mantle rock and bedrock as to porosity. (*b*) Distinguish between porosity and perviousness. Give examples.

4. (*a*) Describe the way in which rain goes down into the mantle rock. (*b*) Explain what is meant by (1) ground water; (2) saturated; (3) water table. (*c*) What factors determine the position of the water table? (*d*) Where does ground water go to?

5. (*a*) Describe the formation of a hillside spring. (*b*) Discuss the purity of spring water. (*c*) Explain the relation of an ordinary well to the water table. (*d*) Copy and learn Figure 6–3.

6. (*a*) Explain what is meant by an artesian formation, with its aquifer and cap rock. (*b*) Describe the artesian formation east of the Rocky Mountains.

7. (*a*) Define and explain what an artesian well is, and how it differs from an ordinary well. (*b*) Name three respects in which artesian wells may be superior to ordinary wells. (*c*) How do the artesian wells of Long Island differ from those of Australia? (*d*) Copy and learn Figure 6–5. (*e*) What is a fissure spring?

8. (*a*) Explain the formation of oil and gas wells. (*b*) What makes the difference between an oil gusher and an oil well that must be pumped?

9. (*a*) Why does spring water or well water seem so cold in summer? (*b*) Why doesn't well water freeze in winter? (*c*) Explain why well water is warmer in Florida than in Quebec.

10. (*a*) Why is the water of deep artesian wells and fissure springs *warmer* than ordinary well and spring water? (*b*) Explain the source of the heat of boiling hot springs and geysers. (*c*) What is a geyser? (*d*) Where do geysers occur? (*e*) Explain the action of a geyser.

11. (*a*) What factors determine the amount and kind of mineral matter dissolved in ground water? (*b*) What is hard water? (*c*) Compare the water of ordinary wells, artesian wells, and rivers in hardness. Explain. (*d*) Why is all the water hard in a limestone region?

12. Describe the different kinds of mineral springs.

13. (*a*) Explain how ground water forms sink holes, caverns, natural bridges, and sink-hole ponds. (*b*) Name several areas in the world where limestone caves are found. (*c*) Why are limestone caves so common?

14. (*a*) Explain how stalactites and stalagmites are formed? (*b*) Explain the origin of travertine, geyserite, mineral veins, and petrified wood.

15. (*a*) Why is the water table dropping steadily in some areas? (*b*) What special problems arise in connection with artesian wells in city areas and coastal regions? (*c*) Name three methods of conserving ground water.

GENERAL QUESTIONS

1. In regions of cold climates, less water enters the ground during winter than in any other season. Why?

2. Why are igneous and metamorphic rocks so low in porosity?

3. Why would a single dry year in the outcrop area of an artesian formation have little effect on distant wells?

4. What disadvantages may artesian water have as compared with ordinary well water?

5. All oil gushers eventually have to be pumped. Why?

6. Why are springs very rare at the tops of mountains?

7. No matter how deep an artesian well is, its water is never very hot when it reaches the surface. Why?

8. Is a rainy climate necessary for the formation of limestone caves? Explain.

9. In some regions petrified wood is composed of silica, a form of quartz. In other regions it is composed of calcite. Why?

STUDENT ACTIVITIES

1. Performing experiments to determine the percentage of pore space in rock materials such as gravel, sand, clay, sandstone, etc.

2. Comparing the perviousness of rock materials

3. Making clay models and working models of the water table and artesian formations

4. Removing the dissolved matter from well or spring water by evaporation

5. Showing how hard water and soft water behave with soap

6. Softening hard water

7. Collecting pictures of caverns, geysers, springs, and oil wells

8. Collecting samples of ground water deposits

SUPPLEMENTARY TOPICS

1. The Geysers and Hot Springs of Yellowstone National Park
2. The Petrified Forest of Arizona
3. Deep Artesian Wells
4. The Origin of Petroleum and Natural Gas
5. Oil-Well Rock Structures
6. Famous Caverns
7. Spas
8. Underground Rivers
9. Mineral Veins
10. Geyser Action

TOPOGRAPHIC SHEETS

1. *Sink holes:* Mammoth Cave, Kentucky; Big Clifty, Kentucky; Arredondo, Florida

2. *Springs:* Camp Mohave, Arizona—Nevada—California

SUGGESTIONS FOR FURTHER READING

The Occurrence of Ground Water in the United States (Water-Supply Paper 489), by O. E. Meinzer. United States Geological Survey, 1923.

Ground Water, by C. F. Tolman. McGraw-Hill, New York, 1937.

(*Also see list at the end of Chapter* 5.)

Chapter 7

THE WIND AND LAND FORMS

1. Regions of wind activity. No part of the earth's surface is completely untouched by the erosional activities of the wind, but the work of the wind is most conspicuous and most effective in regions where the mantle rock is dry, loose, and unprotected by natural vegetation. Mantle rock of this description is found to some extent in all parts of the world, regardless of climate. Most extensive, of course, are the great sandy deserts of the arid regions of the world, in which millions of square miles of the surface are dry and barren for almost the entire year. Smaller areas occur in semi-arid regions such as the driest parts of the Prairies and in the Great Plains of the United States, where periodic droughts may dry out the top soil and kill the plants that ordinarily hold it together. Even in humid regions such as eastern Canada, broad areas of dry loose mantle rock occur in glacial sand plains and around lakes and the ocean.

2. Winds remove mantle rock. Loose, dry, mantle rock is easily picked up and carried off by the wind. Only light winds are needed to pick up clays and silts and to blow them away in the form of dust. Strong winds can carry sand as well, keeping this heavier material fairly close to the surface while blowing great clouds of dust high in the air. Whenever the wind removes mantle rock from a region, it erodes the land by lowering its surface.

In many desert areas the sands and clays formed by weathering are so thoroughly removed by the wind that only pebbles, boulders, and bedrock are left on the surface. This is commonly called a *desert pavement*. Stony deserts of this type are common in southwestern United States and northern Africa. More frequently, however, only the clay and silt are blown out of the desert during great *dust storms*, and the surface is left covered with sand.

In semi-arid regions like the Great Plains, strong winds blowing steadily during periods of drought may remove millions of tons of fine topsoil, sometimes carrying it thousands of miles away. A series of such *dust storms* caused tremendous losses in large parts of the states of Colorado, Kansas, Nebraska, Oklahoma, Missouri, Texas, and South Dakota during the middle 1930's when these areas became known as the Dust Bowl. The wind may also form small saucer-shaped hollows called *blowouts* in places where the mantle rock is more easily removed than elsewhere.

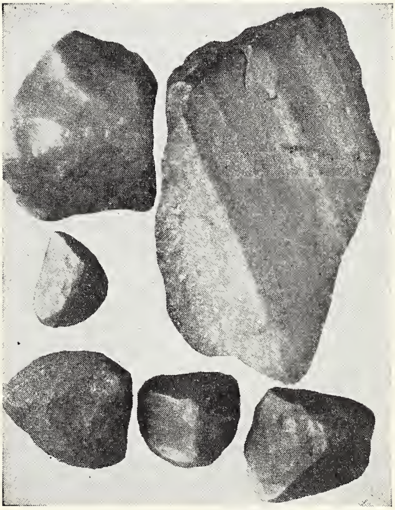
3. Winds grind away bedrock. The sand carried by winds acts as an *abrasive*, or scouring agent, so that winds can

French Press & Information Service

Fig. 7–1. French colonial troops riding over the stony surface of the North African desert.

wear rock down as well as carry it off. The abrasive action of wind-driven sand is illustrated in many ways. Wooden telegraph poles in desert regions are worn away close to the ground until they topple over. In a single desert sandstorm an automobile windshield may be so scratched by sand that it is impossible to see through it. The effects of wind abrasion on rock are slower, but almost as dramatic. Pebbles in desert regions are scoured into flat-sided, sharp-edged forms resembling Brazil nuts, and known as *dreikanter* (*drei,* three; *kanter,* edges). Rock formations are eaten away at their bases, especially in their softer clay or shale layers, leaving masses shaped like toadstools. New sands and clays are formed from the eroded rocks, while the grinding sand may itself be worn down to finer particles.

Since sands are comparatively heavy and are ordinarily not lifted very high, most wind abrasion is performed fairly close to the ground. *Sandstorms* occur when violent desert winds carry the sands to much greater heights and distances than usual.



U.S. Geological Survey

Fig. 7–2. Dreikanter. Pebbles shaped by wind abrasion.

Fig. 7–3. The results of wind erosion on the bedrock of Toadstool Park, Nebraska.

4. Occurrence of sand dunes. *Sand dunes* are hills of sand formed by wind deposition. They originate when sand carried by the wind is piled up against any kind of obstruction, such as a rise in the ground, a boulder, a bush, a fence, or a house. Sand dunes form wherever there are strong winds and a sufficient amount of loose sand. There are three major types of areas in which these conditions are met. They include great sandy deserts like those of Sahara, Peru, southwestern United States, Australia, and South Africa; the sandy flood plains of rivers like the Columbia River in Washington, which, being in a semi-arid climate, are comparatively dry a large part of the year; sandy beaches along sea coasts and lake shores, such as parts of the shores of the Gulf of St. Lawrence and both sides of Lake Huron.

5. The shape and size of sand dunes. If the wind blows steadily from a single direction, dunes develop a long gentle slope on the windy or *windward* side, and a shorter steep slope on the sheltered or *leeward* side. On the shores of Lake Michigan, where the winds are chiefly from the west, the dunes have gentle slopes on their west sides and steep slopes on their east sides. In the deserts of Peru where winds blow steadily from the east, just the opposite is true. Where winds are irregular in direction, sand dunes will not show any distinctly steep or gentle slope. Steady winds of medium strength often form beautiful crescent-shaped dunes called *barchanes* (*bar* kane). (See Figure 7–5.) The windward and leeward slopes of a sand dune are often duplicated in miniature by tiny *sand ripples* formed on the windward surface of the dune. These can also be seen on the loose dry sands of almost any beach after a windy day.

Dunes vary in size from tiny beach dunes a few feet high to mountainous dunes in the Sahara more than a thousand feet high and miles long. Dunes always occur in groups which may cover extensive areas. In the Sahara they cover over 300,000 square miles of the surface.

6. Migration of dunes. Each time the wind blows against the windward side of a sand dune, some of the loose surface sand is carried over the top, where it falls down on the leeward side. As this process continues over a long period

National Park Service

Fig. 7–4. Sand dunes of gypsum sand in White Sands National Monument, New Mexico. The wind blows steadily from the left. Notice the sand ripples on the surface of the dune in the foreground, and the sharp contrast between the gently sloping windward sides and the steep leeward sides of the dunes.

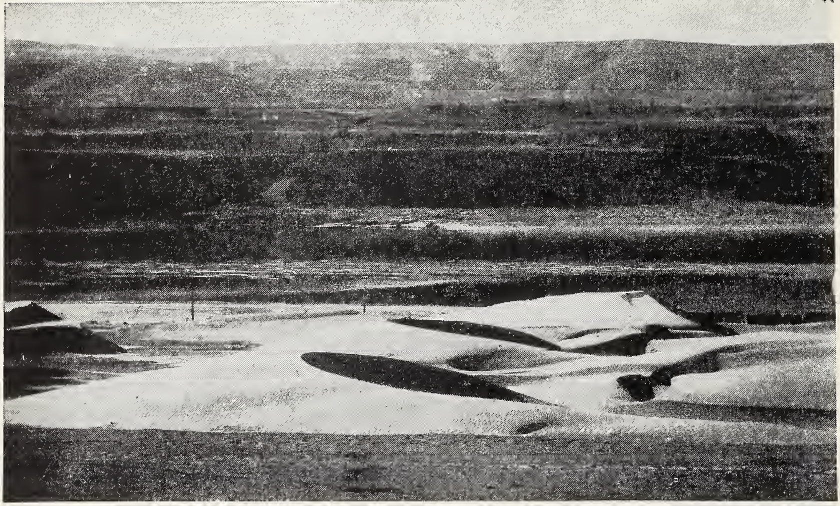
of time, the effect is the same as if the whole dune has been moved somewhat from windward to leeward. This movement is known as *dune migration,* and may amount to as much as 100 feet a year.

There have been many cases where migrating dunes have buried towns, farms, and forests. On the western shores of Lake Michigan, where winds from the west can only blow the beach sand into the lake, no dunes of any consequence form. On the eastern shores, however, the same westerly winds have built up an extensive series of dunes which are migrating inland, gradually burying the trees of a forested area known as Dune Park in Indiana.

Not all dunes migrate. Where grasses and shrubs grow in the dune sands, their roots may prevent further migration of the dune. Grasses and shrubs have been planted on dunes to prevent their drifting over roads and buildings in beach developments as on Cape Cod in Massachusetts and on glacial sands in southern Ontario.

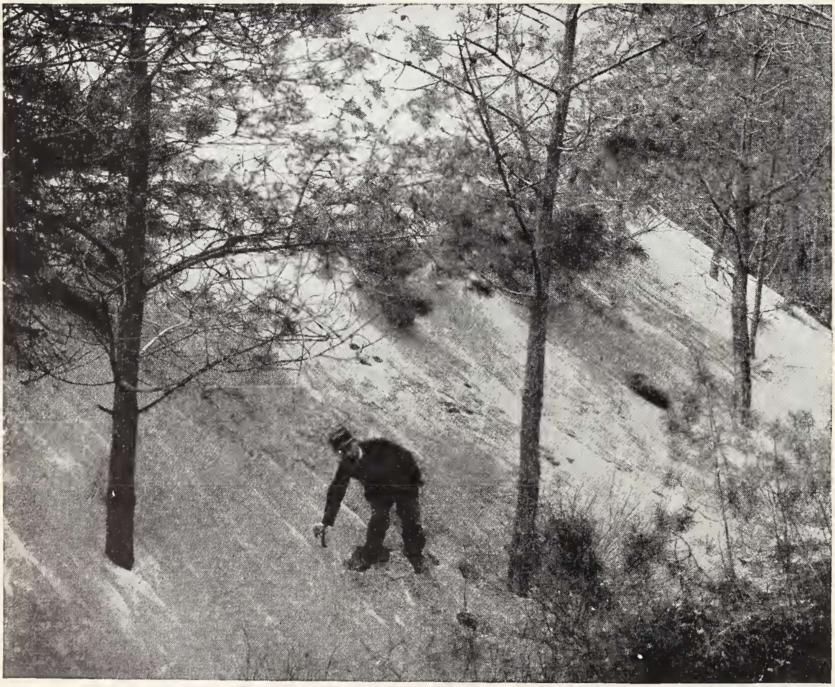
7. Sand dune materials. The term *sand* suggests a particular size of rock particle, rather than a particular kind of material. Sand dunes may be made of any kind of sand. Most dunes are composed of quartz grains, since this is the commonest kind of sand. However, there are exceptions, and the beautiful white dunes of the White Sands National Monument near Alamogordo, New Mexico, where the world's first atomic bomb was exploded, are composed of gypsum sands. Bermuda's sand dunes are composed of calcite sands, eroded from its coral limestone bedrock.

8. Loess. Large areas in China, north-



U.S. Geological Survey

Fig. 7–5. Perfect crescent-shaped barchane dunes on the flood plains of the Columbia River in Oregon. Notice again the sharp contrast between the windward (left) and leeward sides of these dunes.



U.S. Forest Service

Fig. 7–6. The steep leeward side of a sand dune advancing over a pine forest near Arachon, France.

U.S. Geological Survey

Fig. 7–7. Eroded loess deposits at Vicksburg, Mississippi form cliffs as vertical as those of bedrock.

ern Europe, north-central United States, and many other parts of the world, are covered by wind deposits of *loess* (luss) up to several hundred feet in thickness. These loess deposits are composed of an unstratified yellowish silt which holds together so well that when eroded, it splits off vertically to form almost perpendicular slopes. The silts are believed to have been carried by the wind from two different sources. Those of Northern China were blown out of the desert regions of Mongolia, while those of northern Europe and central United States were blown out of deposits left by retreating glaciers during the Ice Age. The loess deposits form unusually rich soils.

HAVE YOU LEARNED THESE?

Meanings of: sand dune, windward side, leeward side

Explanations of: conditions favoring wind erosion; how winds erode; how sandy and rocky deserts form; dust storms; dreikanter, toadstool rocks; origin, occurrence, shape, and migration of dunes; what loess is

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) What mantle rock conditions favor wind erosion? (*b*) Name the three great types of regions in which mantle rock conditions favor wind erosion.

2. (*a*) What mantle rock materials may be removed by the wind? (*b*) Explain why some deserts are sandy and others are stony. (*c*) How may removal of mantle rock damage a semi-arid region? (*d*) What is a blowout?

3. Describe three physiographic effects of abrasion by wind-blown sand.

4. Define sand dunes, describe their origin, and explain where they occur.

5. (*a*) Describe the shape of a sand dune formed by steady winds. (*b*) What effect does wind direction have on the shape of sand dunes? (*c*) What are sand ripples? (*d*) How large are dunes?

6. (*a*) Explain the migration of a sand dune and its effects. (*b*) Why do sand dunes occur on the eastern rather than the western shores of Lake Michigan? (*c*) How may dune migration sometimes be prevented?

7. Explain what materials sand dunes are composed of.

8. Describe the origin, characteristics, and occurrence of loess.

GENERAL QUESTIONS

1. Can toadstool rocks form as well in igneous rocks as in sedimentary rocks? Explain.

2. Why doesn't vegetation protect beach areas in humid climates from wind erosion?

3. Make sketches showing where the windward and leeward sides of sand dunes are for winds blowing steadily from (*a*) the north; (*b*) the south; (*c*) the east; (*d*) the west.

4. How long would it take a set of dunes a mile in length, migrating 100 feet a year, to uncover a house that has just been buried?

STUDENT ACTIVITIES

1. Studying topographic maps of sand dune areas
2. Performing experiments to determine the shape of a sand dune under varying conditions, and to study dune migration
3. Field trips to study dunes at beaches, etc.
4. Taking and collecting photographs of sand ripples, dunes, and other wind-formed features

SUPPLEMENTARY TOPICS

1. The Dust Bowl
2. Dust Storms
3. Sand Storms
4. Dreikanter Formation
5. The Shape and Size of Sand Dunes
6. Sand Dune Areas
7. The Origin of Loess
8. The "Garden of the Gods" in Colorado; Other Examples of Wind Erosion

TOPOGRAPHIC SHEETS

Sand dunes: Parkhill, Ont. 40P/4W; Yuma, California—Arizona; Cape Henry. Virginia

See list of suggestions for further reading at end of Chapter 5.

Chapter 8

RUNNING WATER AND LAND FORMS

STREAM EROSION AND TRANSPORTATION

~~1. Running water and its work~~. Running water is regarded as the most effective of all agents of erosion in wearing down the surface of the earth. Running water includes all the water that falls on the earth's surface as rain or snow and then moves downhill under the pull of gravity. The water trickling out of a hillside spring, the tiny brook flowing out of a pond, the overflow from a swamp, the runoff from melting snow, the rain washing down a hillside, the stream or creek or river running within its banks, or the same creek or river transformed into a torrent that floods its entire valley—all these are forms of running water.

The physiographic work done by running water is usually divided into erosion, transportation, and deposition. *Erosion* (uh *roh* zhun) includes *down-cutting* or the wearing away of the river bed as well as *side-cutting* or the wearing away of the river banks. *Transportation* refers to the carrying away of rock material, while *deposition* refers to the dropping of this material. To some extent, every stream does all of these jobs, but some activities are more conspicuous at one time than another.

2. River terms. Although many common everyday words are used in discussing the work of rivers they should be precisely defined to avoid misunderstanding or improper usage. The word *stream* means any appreciable flow of water. Streams are said to be *permanent* when their flow continues all year, and *intermittent* when they are dry for a part of the year. Many terms are used to indicate streams of different size, the most common being *river* for large streams, *creek* for smaller streams, and *brook* for still smaller ones. No exact size is indicated by these terms, however, and "one man's creek may be another man's river."

All streams flow downhill, which may be in any direction on a map. On a map of Canada the Fraser River flows "down" to the south, the Mackenzie flows "up" to the north, the Great Whale River in Quebec flows "left" to the west, and the Saskatchewan River flows "right" to the east. All these rivers are flowing downhill from high land toward the ocean.

The *source* or *head* of a river is the place where it first makes its appearance on the earth as a surface stream. It is the highest point of a river. At its source the river may be no more than a tiny stream running down from a hillside spring or overflowing from a mountain pond. The source of the St. John River is in a series of lakes along the Quebec-Maine border, while the source of the Ottawa River is in the lakes of western Quebec. The *mouth* of a river is its

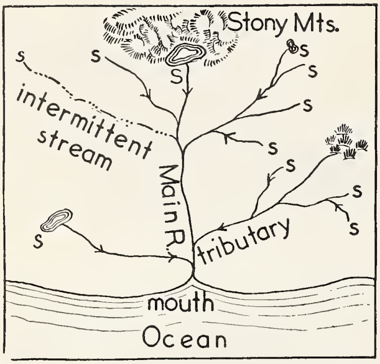


Fig. 8–1. Map of a river system. All of the streams are tributaries except the Main River. Each stream's source or beginning is marked by an S. Each tributary's mouth is at the point where it flows *into* another stream. The arrows show the direction of flow, which is always downhill but may be north, south, east, or west. Since each stream occupies a valley, there must be a divide somewhere between each pair of streams, as well as one that goes all around the entire Main River system.

lowest point or the point at which it ends. The mouth of the Mississippi is in the Gulf of Mexico; the mouth of the Missouri River is in the Mississippi, into which it flows at a point seventeen miles north of St. Louis; the mouth of the Nile River is in the Mediterranean Sea; the mouth of the Niagara River is in Lake Ontario.

A *tributary* is a river that flows into and joins another river which is usually larger and is called the *main stream* or master stream. The Ohio and the Missouri rivers are tributaries of the Mississippi. The *headwaters* of a river include those tributaries which are close to its head or source. A *river system* includes a main river and all of its tributaries. A *river's drainage basin* or *watershed* includes all of the land whose rainfall drains (runs) into the river, either directly or through its tributaries. The Mississippi's drainage basin, for example, includes almost all of the United States from the Rockies to the Appalachians. A *divide* is the high land that separates one drainage basin from the next. We often speak of the Rocky Mountains as the Continental Divide, because its ranges split the continent into two drainage basins. In Canada, rain falling east of this Divide runs into either the Saskatchewan system and Hudson Bay, or further north, into the Mackenzie system and the Arctic Ocean. Over a small area in southern Alberta it runs into the Mississippi system. Rain falling west of the Divide eventually runs into the Pacific Ocean.

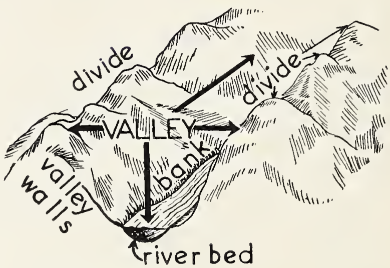


Fig. 8–2. Some of the features of a river valley.

A *river valley* is a lowland between the hills of a drainage basin, at the bottom of which a river runs. The valley is usually carved out by the river itself, though occasionally rivers flow in valleys formed by other natural agents. The *bed* or *channel* of a river is the part actually covered by its running water. (The word *channel* is also used for the deepest part of a river bed.) The river's *banks* are the land running alongside the river and just above it. The rock material carried by a river is called its *load*.

3. Where does river water come from? It is easy to understand why a

river should flow during and shortly after a rain. But where does the river's water come from in the period between rains? There are three supplies. Rivers like the Niagara River and the St. Lawrence River are permanently supplied with water by the Great Lakes at their sources. The Niagara River starts out as the overflow or *outlet* of Lake Erie; the St. Lawrence River starts out as the overflow of Lake Ontario. Lakes as large as these vary so little in level that their outlets have a very even flow of water throughout the year.

The small streams of mountains and forests are steadily supplied by ground water that trickles into their sources—springs, swamps, or small ponds high in the hills or mountains. If the water table drops too low or disappears completely during dry seasons, streams of this type run dry for part of the year, and become intermittent. In desert regions there are intermittent streams which flow only when there are heavy rains, for there is no ground water to provide a flow at other times.

Large rivers like the Mississippi receive their water from thousands of tributaries scattered widely over tremendous drainage basins, and there is scarcely a time when it is not raining over some part of these basins. Such rivers vary enormously in volume, however, and may be subject to destructive floods at times when heavy rains fall over large parts of their vast watersheds.

Still another source of permanent water supply is the melting of snow and ice in high mountain areas. The Rhone River of Switzerland and France is constantly supplied by the melting of the Rhone Glacier from which it starts. In Canada the Yukon River receives its permanent supply from the melting ice and snows of the Coast Range.

4. How water wears the land. Like the wind, running water wears down the surface of the earth by removing mantle

Fig. 8–3. The great rivers of Canada.

rock and by wearing down bedrock. Rain running down a hillside carries loose mantle rock to the bottom of the hill and into the nearest stream, while streams themselves wash mantle rock from their banks and beds. The mantle rock of the hillsides is not easily washed away as long as it is held together by the roots of grasses, shrubs, or trees, but in areas from which this protective vegetation has been removed, rain may cause serious soil erosion.

Running water may break up the bedrock by both mechanical and chemical means. Its mechanical work is accomplished largely through the use of sand, pebbles, and even boulders as *cutting tools* with which it grinds away the rock of its bed and banks. Running water may also split off chunks of the bedrock by its lifting effect as it runs into cracks in the rock. As running water rolls, drags, and pushes rock fragments over its bed, it wears off their corners and edges, eventually producing the rounded boulders, pebbles, and sands characteristic of stream abrasion.

The chemical action of running water is like that of ground water. Running water may break up bedrock chemically by dissolving its soluble minerals. Limestone, marble, and sandstones with soluble cements are the rocks most readily attacked by this process of *solution*. Rivers flowing over such bedrock form pits and holes in their beds.

5. Materials carried by streams. Like all agents of erosion, streams not only wear rock down but also carry it off. Streams transport rock material in three different ways. Clay, silt, and sand, the sediments that give a muddy appearance to the water in which they "hang" between the surface and the bottom, are light enough to be carried in *suspension* by most streams. Pebbles, boulders, and heavy sands are ordinarily moved by *rolling* or pushing along the bed of the stream. In addition to these visible rock fragments, large quantities of invisible mineral matter are carried in *solution*. It is estimated that the rivers of the United States carry a billion tons of rock into the oceans each year, of which about half is in suspension, one-fourth is in solution, and one-fourth is carried by rolling along the bed. Large as this figure is, it represents a wearing down of the entire surface at the rate of only 1 foot in 8000 years, emphasizing once again the slowness of physiographic change.

6. Carrying power and load. The carrying power of a stream depends simply on its *volume* (how large it is) and its *velocity* (how fast it runs). The larger it is and the faster it runs, the more it can carry. The *size* of the largest rock particle it can carry depends on its veloc-

Fig. 8–4. A powerful young stream using boulders and pebbles to grind away its bed. Mistaya Canyon in the Canadian Rockies.

Courtesy Canadian Pacific Railway

ity, increasing amazingly as velocity increases. A slowly moving river, no matter how large it is, may be able to carry nothing larger than silt, while a small swift stream may carry large boulders. At high speeds in flood times, rivers strike obstructions with such terrific force as to be able to tear away steel and concrete structures and move gigantic boulders. The velocity of a stream depends chiefly upon the steepness or *gradient* of its bed, but it also increases with increased depth, as in flood times.

The *total* load carried by a stream depends not only on its carrying power, but also on the amount of material available. Materials may be brought in by tributaries, washed or pulled down from the valley sides by rain and gravity, or eroded from its bed and banks by the river itself.

~~7. Rate of erosion.~~ Every river flows downhill under the pull of gravity until it reaches its mouth. As it flows it wears down its bed. But it can never cut its bed any lower than the level to which it flows. This level is called *base level*. For rivers that flow into the ocean, base level is the same as sea level. Rivers that flow into lakes or other rivers usually have higher base levels, though these may change in time as the level of the lake or main river changes.

The rate at which a river wears down its bed differs from river to river and from one part of the river bed to another. It depends upon many factors, chief of which are the velocity of the river, its volume, the kind of rock over which it runs, and its supply of cutting tools. A river that carries no cutting tools can perform little erosion; one that has received more sediment from its tributaries than it can carry scarcely erodes its bed at all, dropping sediment in it instead. Such a river is said to be *overloaded*. Except at flood times, it winds in and out between so many sand bars that it is often described as a *braided stream.*

SHAPING THE VALLEY

8. The steep V-shaped valley. As running water in any form moves over the surface of the earth, it wears out a depression or *valley* which is usually V-shaped in cross section, though the sides of the V may vary tremendously in steepness (see ~~Figure 8-5~~). The cross section of a valley is a line drawn down one side of the valley, across the river, and up on the other side of the valley. The V-shape of a river valley is explained by the fact that *while the river deepens its valley by eroding its bed, it also widens its valley by eroding its banks.* In the widening process it is assisted by weathering, gravity, rain, and tributaries. Since the upper valley walls are the first to be exposed as the river erodes its bed, they are attacked sooner than the lower valley walls, thus making the valley wider at the top than at the bottom.

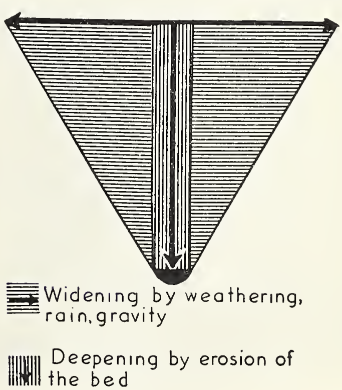
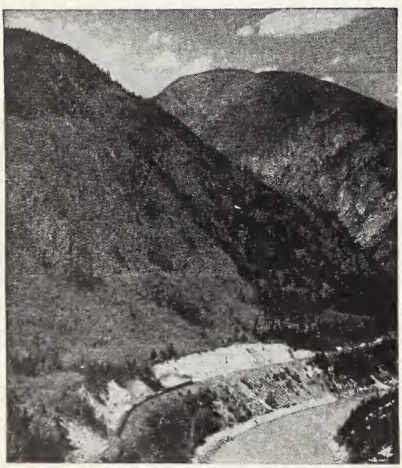


Fig. 8–5. The origin of a V-shaped river valley. As the young river erodes its bed, other natural forces wear away the exposed walls of the valley.

The steepness of the cross section of a valley depends upon the *relative speed* of deepening by the river and widening by the other forces. If no widening at all took place, a vertical-walled valley would be formed which would be no wider at the top than at the bottom. The nearest approach to this in nature is generally found in high arid plateau regions like those of southwestern United States, where steep swift rivers cut rapidly through the rocks to great depths, while widening of the valley by weathering and rain is extremely slow because of the dry climate. But even in humid regions, the combination of rapid erosion of the bed and slow widening of the valley occurs. The deep, steep-sided valleys thus formed are known as *canyons* or *gorges*. Other names with similar meanings are ravine, chasm, and glen.

Greatest of all canyons, though not the steepest, is the Grand Canyon of the Colorado River in Arizona, part of which has been set aside as a national park. Varying in depth from 4000 to 6000 feet, and in width from 7 to 15 miles, the canyon runs 200 miles through the Colorado Plateau in northern Arizona. Other superb examples of cliff-walled river valleys are the canyon of Fraser River in British Columbia and the Nahanni River through the Mackenzie Mountains. In the east there are also spectacular river valleys; these include the Hamilton River below the Grand Falls in Labrador, the St. John River below Grand Falls in New Brunswick, and the Niagara Gorge.



National Film Board, Canada

Fig. 8–6. The canyon of the Fraser River near North Bend, B. C. Notice the very steep V formed by the valley walls in the background.

9. Widening ~~of the valley.~~ River valleys do not remain steep-sided forever. The deeper the river cuts into its valley, the closer it approaches the base level below which it cannot erode its bed. The slope of the river decreases, its speed decreases, and it cuts down more and more slowly. But while deepening of the valley by the river is thus being checked, weathering and gravity go on as before with their work of widening the valley, and they "catch up." The result is a gradual but continuous change in the shape of the V. As the valley walls wear down, the valley becomes greatly enlarged. Its cross section remains a V, but the walls of the V become increasingly gentle in slope (~~see Figure 8–7~~).

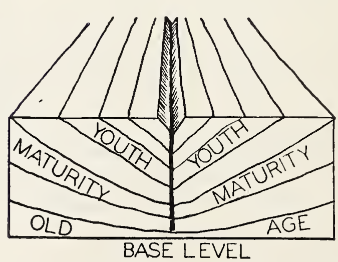
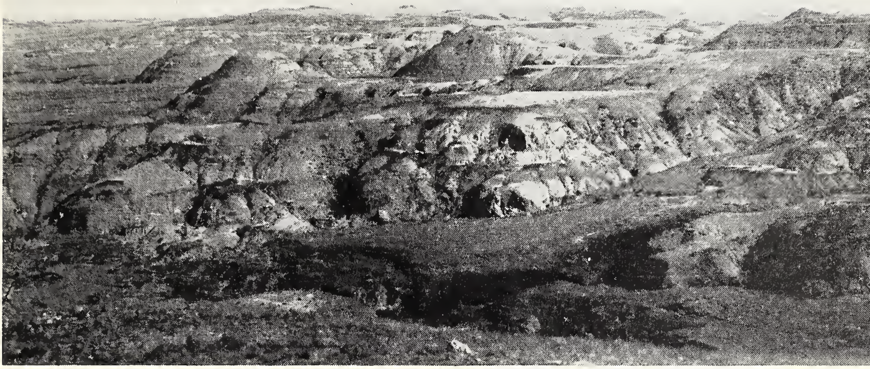


Fig. 8–7. How the cross section of a river valley changes with time.



C. M. Sternberg, Geological Survey of Canada

Fig. 8–8. Badlands in the vicinity of Rocky Creek, Saskatchewan.

Weathering, gravity, and their allies in the work of wearing away the valley walls have plenty of time to "catch up." It is estimated that much less than one-tenth of a river's life history is spent in the canyon-shaped valley which it can produce only while flowing rapidly down steep slopes. The actual number of years varies with the river. A great river like the Colorado may take millions of years to form a canyon a mile deep in a plateau of hard rock, while a small stream flowing over soft clays may end its canyon stage in a hundred years.

LENGTHENING THE VALLEY

~~10. Gullies and headward erosion.~~ A single heavy rain that runs down a hillside of loose mantle rock may erode a miniature river valley in the hillside. Like larger river valleys, this valley will be V-shaped in cross section and may have a number of tributaries. When the rain ends, the "river" disappears, but its tiny valley remains and is known as a *gully*. Gullies may be seen on farm land, at roadsides, in deforested areas, and, in fact, in any place where heavy rains may wash mantle rock away from some part of a sloping piece of land.

Courtesy Caterpillar Tractor Co.

Fig. 8–9. Gullies forming a miniature river system on easily eroded soil in Maryland.

Gullies may be only a few feet long and a few inches deep, or they may be hundreds of feet long and many feet deep (~~see Figure 8–9~~).

Gullies grow in length, width, and depth with each new rainfall and even between rains. When it rains, water runs into the head and sides of the gully from higher parts of the hillside. As this water runs into the gully, it washes in some of the surrounding mantle rock. The result of this action is both a widening and a lengthening of the gully. Each rain moves the source of the gully farther up the hillside, making the gully longer than it was before the rain (~~see Figure 8–10~~).

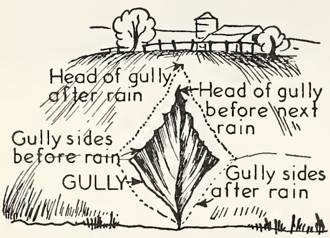


Fig. 8–10. The lengthening of a gully by headward erosion.

Slight changes in the size of a gully may also be brought about between rains by the action of weathering, gravity, and the wind. *Headward erosion* is all the processes that work together to wear away the land *at the head or source of a gully.* This includes the work of rain wash, weathering, gravity, and wind. The stream flowing in the gully plays no part itself in headward erosion, although it benefits from it in the lengthening of its valley. *Headward erosion does not mean that the stream is flowing toward its head.*

Gullies may be considered to be the valleys of intermittent streams. As a gully grows in length and depth, it may cut below the water table and become a permanent stream. Tributary gullies may join it, and in time a complete river system may be born. Most of the world's rivers are believed to have originated in this simple way. A river whose source is a hillside spring may continue to lengthen by headward erosion until its source reaches the divide that separates the drainage basin of the river from the neighboring one. Similar growth of tributary rivers enlarges the entire river system.

Large numbers of gullies develop in regions of soft, nonporous clay deposits unprotected by vegetation. Such regions are so difficult to travel through that they are called *badlands.* Among the best known badlands are those of South Dakota and Nebraska. Smaller areas are found in the Southern Prairies.

11. Rivers can be pirates. *Stream piracy* or *stream capture* results from the lengthening of a river by headward erosion. Figure ~~8–11~~ illustrates one way

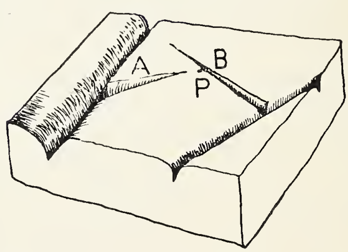


Fig. 8–11. As stream valley *A* is lengthened by headward erosion, it may cut into valley *B* at point *P*, thereby diverting *B's* headwaters. This is known as stream piracy. (See Topic 11.)

in which stream piracy occurs. As the source of tributary A moves farther and farther up the slope on which it originates, it cuts into the banks of tributary *B* of another river. If, as headward erosion continues, A's source wears down lower than *B*'s bed at point *P*, all of

B's water above point *P* will eventually flow into *A*. If the difference in level at *P* is large, there may be a waterfall at *P*. Stream *A* is known as the pirate stream and stream *B* as the captive stream. By such a process, one stream may grow larger at the expense of the neighboring ones, and it is probable that many of the great river systems of the world were aided in their development by stream piracy.

Stream piracy may be regarded as a result of differences in the rate of stream erosion, since the pirate stream must cut down its bed faster than the stream it captures. More rapid erosion by the pirate stream may be the result of steeper slope, softer rock, or greater volume. Many interesting cases of stream piracy are known to have occurred in the Appalachian Mountains of the eastern United States and in the Prairies.

IRREGULAR DEEPENING

12. Potholes and plunge pools. No stream bed is perfectly smooth. As a swift stream moves over the irregular bedrock and boulders in its bed, it develops spirals and whirlpools at many places in its course. If these whirlpools continue in the same places for any considerable length of time and are equipped with ample cutting tools, they grind out more or less circular *potholes* in the bedrock of the stream. The grooves and scratches made by the whirling pebbles and sands can often be seen on the sides of the potholes.

Larger potholes called *plunge pools* may be ground out by giant whirlpools at the bases of waterfalls. Potholes may be seen in almost any rocky stream bed. They vary in size from tiny ones measured in inches to great plunge pools that measure up to 40 or 50 feet in diameter and even more in depth. Covey Hill, on the Quebec side of the Adirondacks,

U.S. Geological Survey

Fig. 8–12. Potholes in the granite bed of the James River, Virginia. These potholes were eroded by whirlpools in the river during periods of higher water.

and lakes in the Grand Coulee in the state of Washington, occupy plunge pools made by great waterfalls in the beds of rivers that no longer exist.

13. Waterfalls and rapids. River beds rarely maintain the same slope for any very great distance. On the average, the slope is likely to be steepest in the headwaters of a river and gentlest near its mouth. At some points the river bed may be so steep that *rapids* are formed. Where the river bed is vertical or nearly vertical, the water plunges over a cliff to form a *waterfall*.

The steep slopes and cliffs that are responsible for rapids and waterfalls may originate in many different ways: through earthquakes, volcanic action, unequal weathering, or unequal erosion. In some cases the steep slopes and cliffs were parts of the surface topography when the rivers first started to flow. Niagara Falls came into existence simply because the Niagara River had to pass over a cliff on its way from Lake Erie to Lake Ontario. But in many cases the river itself, through unequal erosion, has worn steps or cliffs in a bed that was originally uniform in slope, thereby making its own rapids and waterfalls. The falls of the Yellowstone

River in Yellowstone National Park are examples of this method of origin. ~~(See Topic 16.)~~

Like canyons, rapids and waterfalls are regarded as only temporary features in the life of a river, lasting for perhaps no more than the first 5 per cent of the river's complete history. The greater speed of the river at these places causes them to wear down more rapidly than other parts of the bed, and they eventually disappear.

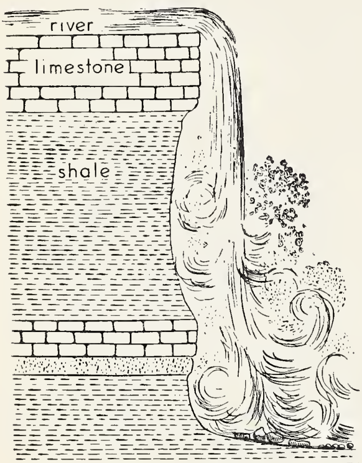


Fig. 8–13. Diagram showing the rock structure of a receding waterfall of the Niagara type. The soft shales that lie beneath the hard limestone cap are easily eroded by the river. As the undermined limestone breaks off, the waterfall recedes.

14. Undermining ~~and recession~~. Waterfalls often grind out potholes or plunge pools at their bases. In many types of waterfalls, these holes *undermine* or weaken the waterfall cliff sufficiently to cause pieces of the cliff top to cave in. Each time this happens, the waterfall is left a little farther upstream than before and is said to recede (move back). Undermining and recession are fastest in waterfall cliffs made of horizontal layers of bedrock with weak bottom layers, and slowest in cliffs made of durable massive rock from top to bottom.

15. Niagara Falls recedes. Niagara Falls is the world's most famous example of the commonest type of waterfall. In this type, the cliff consists of horizontal or nearly horizontal rock layers with a hard cap layer and softer, weaker layers below. At Niagara the cliff is about 160 feet high, the cap is a hard limestone layer about 60 feet thick, and the weaker layers consist largely of thin beds of shale. Great plunge pools, as deep as the falls are high, are formed in the weak shales at the foot of the falls. This undermines the hard limestone cap until from time to time it breaks off because of its own weight, causing the falls to recede (see Figure 8–13).

When the Ice Age ended in North America, Niagara Falls originated at a cliff 7 miles downstream from its present location. It has been estimated that it took Niagara about 25,000 years to re-

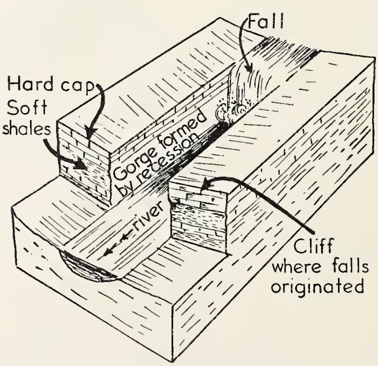


Fig. 8–14. Sketch showing the formation of a gorge by waterfall recession, as at Niagara. The gorge extends all the way from the original position of the fall to its present position.

Courtesy Niagara Falls Chamber of Commerce

Fig. 8–15. Aerial view of the Niagara River, Niagara Falls, and the Niagara Gorge below the falls. Goat Island separates the American Falls in the foreground from the Horseshoe or Canadian Falls in the background. The tremendous spray from the much greater volume of the Canadian Falls always makes it difficult to see.

cede from this original position, near which the city of Lewiston stands today. As Niagara Falls and its plunge pools wore back, they left a great gorge which is now 7 miles long, about 300 feet deep, and from 200 to 400 yards wide.

At its present location, a small island (Goat Island) in the middle of the Niagara River splits Niagara into two falls known as the American Falls and the Canadian Falls. Goat Island extends diagonally across the river in such a way as to make most of the water go over the Canadian Falls. Erosion here is so rapid that the Canadian Falls is receding at the rate of almost 5 feet a year and is now worn back so much that it is also known as the Horseshoe Falls. Recession of the American Falls is much slower, averaging only a few inches a year, and its outline is fairly straight.

16. Yellowstone Falls does not recede. The origin of Yellowstone Falls is a good illustration of the manner in which unequal erosion by a river creates its own waterfalls. At several places in the bed of the Yellowstone River, vertical intrusions (dikes) of lava have formed rock that is much harder than the rest of the bed (see Figure 8–16). The river erodes the soft rock downstream from the intrusions so much more rapidly than the dikes that it develops falls at these points. Since the dikes extend to great depths and are uniformly hard, they are not undermined, and these falls do not recede.

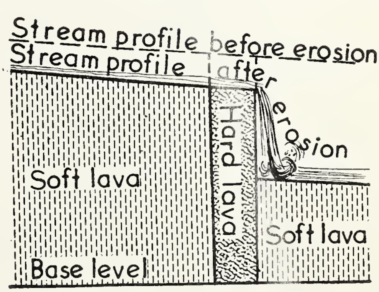
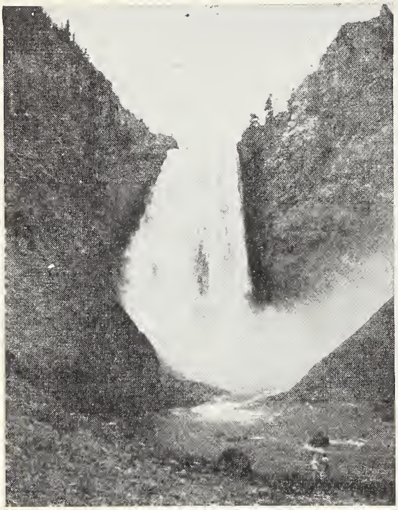


Fig. 8–16. A lava-dike type of waterfall originates through unequal erosion of the hard lava and the softer rock next to the lava in the river's bed. Yellowstone Falls originated in this way.

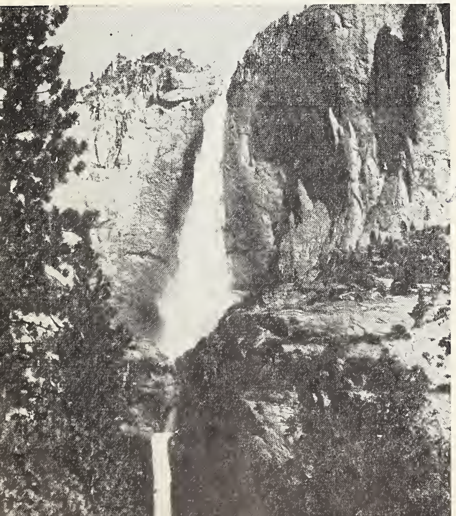


Courtesy The Milwaukee Road

Fig. 8–17. At its Lower Falls the Yellowstone River drops 308 feet over a lava dike. Note the two figures in the right foreground.

Fig. 8–18. From its hanging valley Yosemite Creek plunges 2200 feet to join its main stream, the Merced River. The first drop is 1400 feet; the second is 800 feet. Yosemite National Park, California.

Courtesy Southern Pacific



The Lower Falls of Yellowstone is 308 feet high.

17. Other waterfalls. The Shoshone Falls of the Snake River in Idaho is similar to Niagara Falls as it was caused by hard cap rock on top of soft rock, but its rocks are lavas rather than sedimentary rocks. The great Victoria Falls in Africa occur where the Zambezi River flows from hard rock to soft rock. Streams flowing from the north, along the north shore of the lower St. Lawrence River, form falls and rapids as they leave the hard rock of the Canadian Shield for the soft rock of the Lowlands. These falls and thousands of others are the result of unequal erosion in rocks of unequal hardness.

Many falls occur where tributary streams join main streams whose valleys are cut much lower than those of the tributaries. The tributary valleys are called *hanging valleys*, and the falls *hanging valley waterfalls*. This type of falls occurs frequently in regions of glacial erosion, and its origin is explained in Chapter 9. Many of the great falls in Yosemite (Yoh *sem* ih tee) National Park are of this type. Yosemite Falls, over 1400 feet high, is probably the highest waterfall in the world.

WIDENING OF THE VALLEY FLOOR

18. ~~Flood plain and meanders.~~ A fast-flowing river moves in a comparatively straight course which directs most of its cutting power at its bed. The river deepens its bed, while other agencies widen the valley walls above it, leaving the *floor* of the valley hardly any wider than the river bed itself. But as the slope and speed of the river decrease with the passing of time, its ability to override large boulders, hard rock outcrops, and other obstructions is largely lost, and it is more easily deflected side-

ways against its banks (see Figure 8–20). As the water is deflected against the bank on one side, it erodes that bank and begins the formation of a curve in the river's course. But from this bank it is now deflected diagonally downstream until it strikes the opposite bank, where both erosion of the bank and deflection downstream are repeated. In this way the river begins the development of a curving course which, in time, erodes the floor of the valley to form a wide flat area called a *flood plain*. (This name is given to it because the river overflows onto it during floods. At such times the flood plain is built up higher by sediments which the river deposits. ~~See Topic 24.~~) The process by which the valley floor is widened is called *lateral erosion* or *side-cutting.*

Once begun, the curving course of the river becomes more and more pronounced. At each bend in the river, the current swings against the bank at the *outside of the curve, undercutting it* and eroding it rapidly. At the *inside of each curve,* there is so little water in motion that *sediment is deposited.* The net result is the shifting of the river bed in the direction of the outside of the bend. As this shifting of the bed occurs at each bend on alternate sides of the river, the river's course eventually forms a series of broad curves called *meanders* (~~mee an ders~~), which wind their way across an increasingly broad flood plain. Great Rivers like the Mississippi, the Nile, the Ganges, and the Amazon may have flood plains dozens of miles wide and hundreds of miles long.

Fig. 8–19. A meandering river and its flood plain, Crooked Creek, California. The meander in the left foreground shows plainly its undercut outside bank and its gently sloping inside bank.

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19. ~~Cutoffs and oxbow lakes.~~ As meanders swing wider and wider, their ends move closer together until they almost touch. The land separating the ends of a meander is called its *neck*. Since undercutting is taking place at the banks on both sides of the meander neck (~~see Figure 8–20~~), the river eventually breaks through the neck to form a *cutoff*, at the same time making an island of the land inside the meander curve. Most of the river goes through the shorter cutoff, and the meander becomes an abandoned channel full of sluggish water. Mud and silt are deposited by the river along the old entrances to the meander, which becomes completely separated from the river to form an *oxbow or horseshoe lake.*

Large numbers of oxbow lakes occur on the flood plain of the Mississippi. At flood times, silt is deposited in oxbow lakes, making them shallower. Vegetation grows in them, turning them into swamps or *bayous*, and eventually filling them up completely.

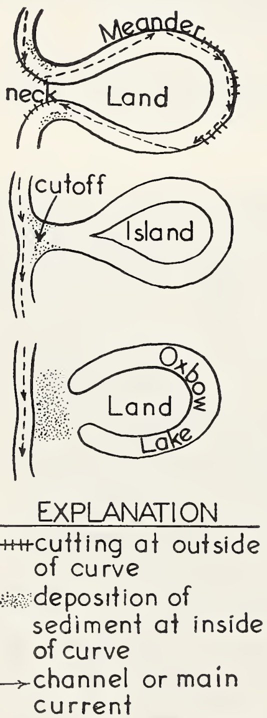

Fig. 8–20. The formation of a cutoff and an oxbow lake from a river meander.

20. ~~Water and wind gaps.~~ In regions where an extensive formation of resistant rock crosses the bed of a river, the river is unable to widen its valley by lateral erosion as fast as it does in the softer rock above and below the formation. But the hard rock formation is also more resistant to weathering, so it usually stands above the rest of the countryside as a mountain or ridge (~~see Figure 8–21~~). Through this ridge, the river runs in a narrow, canyon-like valley which is in marked contrast to its broad, open valley on both sides of the ridge. The cut made by the river through the ridge is called a *water gap* or *narrows.* A famous gap is the Delaware Water Gap in the eastern United States cut by

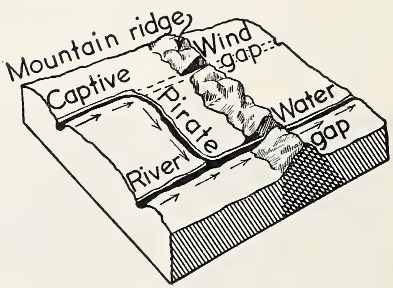

Fig. 8–21. Sketch showing how stream piracy may turn a water gap into a wind gap. The "pirate" is a tributary of the river in the foreground. Through headward erosion it has captured the river in the background. The abandoned water gap then becomes known as a wind gap.

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Fig. 8–22. The foreground shows the Delaware River. In the background is the Delaware Water Gap, cut by the river through the Kittatinny Mountains.

the Delaware River through the hard conglomerate rock of the Kittatinny Mountains in Pennsylvania. Many other gaps occur in the Appalachian Mountains along the Susquehanna, the Potomac, and other rivers.

Wind gaps are simply abandoned water gaps. Many wind gaps occur in the southern Appalachians, where stream piracy has diverted a number of rivers after they had made water gaps.

ALLUVIAL DEPOSITS

21. Reasons ~~for deposition~~. Deposits of sediment by running water are called *alluvium* (~~uh loo vee um~~) or alluvial deposits. Since the total load carried by a stream depends on both *volume* and *velocity,* it is easy to see that any decrease in either will cause the stream to deposit some of its load. The principal reasons for *loss of velocity* are: (1) decrease in slope, (2) obstructions, (3) broadening of the stream bed, (4) loss of water, (5) emptying into a slower body of water. *Loss of volume* may result from: (1) evaporation in passing through a desert area, (2) seepage into porous ground, (3) diversion of water by man for irrigation and other uses.

It has already been pointed out that deposits made by running water are likely to be assorted according to size of particle or to be stratified in layers. Such deposits also contain particles whose edges and corners are rounded off.

22. Deltas. When a river flows into a relatively *quiet* body of water such as a lake, inland sea, or ocean gulf, its loss of velocity is complete, and all of its sediment is deposited at its mouth. The sediment, most often composed of sand, silt, and clay, usually forms a level, fan-shaped deposit called a delta (after its resemblance to the Greek letter delta, Δ). The shape of the delta varies considerably with such factors as the rate at which sediment is deposited and the rate at which it is removed by waves and currents. Deltas are unlikely to form along open ocean coasts because strong waves and currents carry the sediment off too rapidly.

The fan shape of a delta is due to the fact that, as the river's deposits block

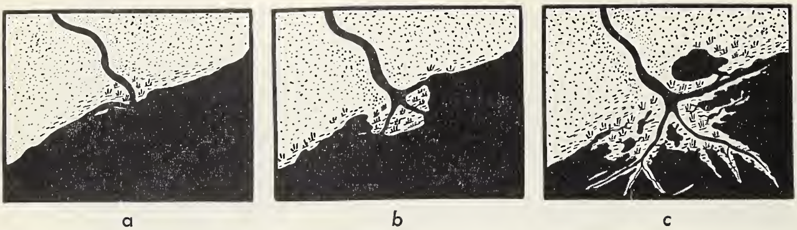

Fig. 8–23. Three stages in the growth of a delta are shown in sketches (*a*), (*b*), and (*c*). Land is drawn in white; water is in black. The branches of the river across the delta are called distributaries.

its mouth, it swerves away from that point, often splitting into two or more branches, and spreads additional deposits on both sides of the center. This blocking and shifting is repeated continually, spreading the sediment out until the fan shape is developed. The branches into which the river divides as it flows over its delta are called *distributaries* or *passes*. Unlike tributaries, they flow away from the main stream rather than into it.

The delta of the Mississippi extends 200 miles into the Gulf of Mexico, covers an area of over 12,000 square miles, and is growing seaward at an average rate of about 350 feet a year. Other great deltas are those of the Nile in the Mediterranean Sea, the Danube in the Black Sea, the Rhine in the North Sea coast of Holland and Belgium, the Ganges and Brahmaputra in the Bay of Bengal, and the Mackenzie in the Arctic Ocean.

Fig. 8–24. Sketch map of the Mississippi River delta. The circled area shows the extreme southern end of the delta in the Gulf of Mexico. Figure 8–25 is a photo of this area.

23. Alluvial fans. Rivers sweeping down from steep mountain valleys onto comparatively level lands suffer great losses in velocity. As they come out of their mountain canyons they drop a large part of their usually heavy loads of coarse sands and gravels at their mouths. These loads form deposits greatly resembling deltas both in shape and in the manner in which the streams divide into distributaries over their surfaces. The deposits are not flat-surfaced like deltas, however, and their sediments are much coarser. When their slopes are only moderately steep, these deposits are called *alluvial fans;* when very steep, they are called *alluvial cones.*

The distributaries often disappear completely into the extremely porous materials of the fans, but emerge down the slope where the fan deposits thin out. Alluvial fans are best developed in the steep mountain areas of western United States, particularly at the bases of the Rocky and Sierra Nevada mountains. Some of these fans attain a diameter of 40 miles, spreading so far along

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Fig. 8–25. Aerial view of the passes at the mouth of the Mississippi River. The area shown in the photograph is circled in the map of Fig. 8–24. The Gulf of Mexico is at the top of the photo.

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Fig. 8–26. An alluvial fan at the mouth of Aztec Gulch, Colorado. The Gulch appears as the dark line cutting diagonally across the mountainside. The front of the fan runs from left to right across the middle of the photo.

the mountain base as to meet and merge with the fans of other rivers. Such a continuous series of fans is known as a *piedmont alluvial plain* (*piedmont*, foot of the mountain).

24. Flood plain deposits. The flood plain has already been explained as the flat portion of a valley floor, formed by lateral erosion and subject to flooding by the river. A river is said to be in flood when it receives more water than it is able to contain within its banks. Because of its greatly increased volume and velocity at flood times, a river carries tremendous quantities of sediment. When it overflows its banks and spreads over its flood plain, sediment is deposited on the flood plain in large amounts, because the waters on the flood plain are shallower and slower than the waters in the river bed. Thus a layer of alluvium is spread over the valley floor with every flood, but some of it may be removed by lateral erosion before the next flood occurs.

The deposit of alluvium is not uniform in either thickness or composition. Since the greatest loss of velocity takes place right at the banks, where the river waters are suddenly transferred from the deep bed to the shallow flood plain, more sediment is dropped here than farther back on the flood plain. Not only is the quantity greater, but the materials are coarser. In this way a thicker deposit is built up all along the banks, forming low ridges called *natural levees* (*lev-ee*) on both sides of the river.

Beyond the levees the flood plain is lower, and in some places the water table may stand above the surface to form areas called *back swamps*. Since the flood plain slopes *away from* the main river, tributary streams may flow great distances through the back swamps before they can cut through the levees to join the main stream. Such tributaries are called *yazoo streams* and are named after the famous Yazoo River, which flows 175 miles through the back swamps of Mississippi before joining the Mississippi River.

Natural levees are never any higher than the height of water during the last flood that built them. To provide further flood protection, natural levees are often built up into *artificial levees*, varying from elaborate concrete walls to simple heaps of sand bags. The "dikes" of Holland are artificial levees on the flood plain of the Rhine River. On many occasions the Mississippi has burst through its levees in great gashes called *crevasses* (kruh-*vass*-es) to cause flood damage far greater than during ordinary

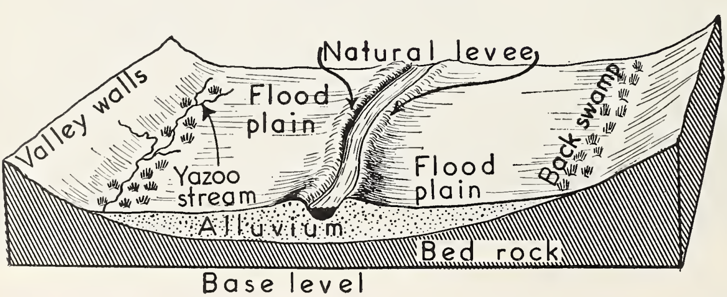

Fig. 8–27. Sketch of a well developed flood plain such as that of the lower Mississippi River.

Corps of Engineers, U.S. Army

Fig. 8–28. The Atchafalaya River of Louisiana and its flood plain. Note the natural levees adjacent to the river, the high straight artificial levees at the center, the oxbow lake and swamp at the left, and the yazoo tributary in the left background.

overflow. In the famous legend of the dikes of Holland, the boy hero strove to prevent just such a catastrophe.

LIFE HISTORY OF A RIVER

25. The three stages. Many years ago the great physiographer William Morris Davis introduced the idea that land forms may be considered to pass through a *life history* (or cycle of erosion) similar to that experienced by living things. The complete cycle of a land form includes its history from the time of its origin or "birth" to the time of its complete removal by erosion or its "death." As with living things, the cycle is usually divided into the three principal stages of *youth, maturity,* and *old age.* These stages do not imply any fixed number of years, but rather a set of characteristics generally associated with these stages in living things. For example, a dog is old at the age of ten, but a human being is still young at that age. Thus a land form that continues to show youthful characteristics is considered to be in youth, regardless of its age in years.

26. Youth. A river that is in the vigorous early stages of its development is a young river. Such a river flows rapidly over a generally steep, but irregularly sloping bed. Its straight course is frequently interrupted by rapids and waterfalls, and occasionally by lakes through which it flows. It has few tributaries. Its chief work is down-cutting. Thus its valley is steep-sided or canyon-like in form, and it has almost no flood plain. The interstream areas (areas between valleys) are comparatively flat, and there are no well-marked highland divides to separate its drainage basin from the next (~~see Figure 8–8~~).

The Hamilton, the St. Maurice, the Ottawa, the Niagara, the Churchill, the Fraser and the Skeena rivers are excellent examples of young rivers. Since headward erosion is constantly adding to the length of a river at its source, the *headwaters* of almost every river are young.

27. Maturity. The end of youth and the beginning of maturity are marked by the elimination of almost all of the irregularities of the bed of a river. Rapids and waterfalls have been worn away, and lakes have been filled in by the river's deposits. The mature river now flows over a smoothly sloping bed which is said to be *graded*. Like a good mountain highway, the bed is nowhere too steep. Having cut the bed down closer to *base level*, the slope is decreased, and down-cutting has given way largely to side-cutting or lateral erosion (~~see Figure 8–19~~). By late maturity the river has developed a meandering course across its broad flood plain, and natural levees, oxbow lakes, and back swamps may be present. The valley cross section shows gentle sides and a flat floor (~~see Figure 8–7~~). Interstream areas are narrow, and the divides are sharp. There are many tributaries, and the increased volume of the river makes up for its reduced velocity in enabling it to transport great quantities of sediment.

Except in their headwaters, rivers that have well-developed flood plains are mature. Thus the Mississippi is young in its hilly headwaters, early mature in its narrower northern valley, and mature to late mature or old in its southern portions. Other mature rivers are the Red, the Missouri, the Nile and the Rhine.

28. Old age. The characteristics of old age differ very little from those of late maturity. The river bed is so close to

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Fig. 8–29. Aerial view showing the Leland and Tarpley cutoffs on the Mississippi River near Greenville. The numerous so-called "Greenville Bends" which existed prior to the cutoffs can be seen by the present appearance of the narrow meander necks. Other bends northward can be seen in the background. The man-made cutoffs have decreased the navigation distance and increased the river's carrying capacity.

base level that there is barely enough slope to keep the river flowing. Fewer tributaries bring in less water and less sediment. Down-cutting has practically stopped, and lateral erosion is less active than in maturity. At this stage the chief activity of the river is deposition. The valley floor is very broad and flat. The valley sides are worn to very gentle slopes, and the interstream areas are so low that divides are again indefinite. The entire valley is worn nearly to base level. In a large region of old rivers, the low rolling surface produced by erosion is so nearly flat that it is called a peneplane (*pee* neh plane). *Pene* means almost; *plane*, flat surface.

There are very few examples of rivers in old age. Erosion is so slow in late maturity that tremendously long periods are required to bring about the characteristics of old age. In most cases the river's life cycle is interrupted by vulcanism or diastrophism long before old age is reached. The lower Mississippi River may be considered, however, as a close approach to the features of old age. Apparently rivers did reach old age in past geologic eras, for raised peneplanes exist in many parts of the world. They will be described in a later chapter.

HAVE YOU LEARNED THESE?

Meanings of: base level, canyon, alluvium, delta, alluvial fan, natural levee, water gap, wind gap, oxbow lake, cutoff, yazoo stream

Diagrams and descriptions of: types of waterfalls; development of oxbow lakes

Explanations of: a river's work; a river's water supply; stream erosion and transportation; valley widening; rate of stream erosion; headward erosion, valley lengthening, and stream piracy; recession and erosion of waterfalls; Niagara gorge; causes and characteristics of river deposition; characteristics of young, mature, and old rivers

Origin of: V-shaped valleys and canyons; gullies; badlands; potholes and plunge pools; waterfalls; flood plain; meanders, cutoffs, oxbow lakes; water gaps and wind gaps; deltas, alluvial fans, flood plain deposits, natural levees, back swamps, peneplanes

Relations between: velocity, volume, and carrying power; slope, volume, and velocity

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) Define running water and name some of its forms. (*b*) What physiographic work is done by running water?

2. Explain or define each of the following, or draw sketches to illustrate them: stream, river, creek, brook, intermittent stream, source, head, mouth, tributary, headwaters, river system, drainage basin, divide, valley, bed, banks, channel, load.

3. (*a*) Explain, with illustrations, what are the three sources of permanent water supply for rivers. (*b*) Compare these sources as to the likelihood that they will cause floods in their rivers.

4. Describe the mechanical and chemical action of running water in (*a*) removing mantle rock; (*b*) wearing away bedrock.

5. Name and describe the three methods by which streams carry rock material. Compare the amounts carried.

6. (*a*) Discuss the way in which volume and velocity control the size of particle and total load carried by a stream. (*b*) What determines a stream's velocity?

7. (*a*) Explain what base level is. (*b*) What factors determine the rate of stream erosion?

8. (*a*) Explain why a young river valley is almost always V-shaped. (*b*) Explain what canyons are, and how and where they are formed. Give examples.

9. Explain why the cross section of a river valley becomes less and less steep with time.

10. (*a*) Explain the formation of a gully. (*b*) Define headward erosion, and explain how it lengthens a gully. (*c*) How are gullies related to the origin of river systems? (*d*) What are badlands?

11. (*a*) Explain how headward erosion may bring about stream capture. (*b*) Why is stream capture an effect of differences in the rate of erosion?

12. Describe the origin of potholes and plunge pools.

13. (*a*) What are rapids and waterfalls? (*b*) How do they originate? (*c*) Why do they eventually disappear?

14. (*a*) Explain why waterfalls often recede. (*b*) In which type of waterfall is recession fastest? slowest?

15. (*a*) Describe the structure of the Niagara type of waterfall. Explain why it recedes. (*b*) Explain how the Niagara gorge was formed. (*c*) Explain why the Canadian Falls recedes so much more rapidly than the American Falls.

16. With the aid of a diagram, explain the origin of Yellowstone Falls. Why doesn't it recede?

17. (*a*) Compare the structure of Shoshone Falls, or the Victoria Falls, with that of Niagara. (*b*) Describe the type of falls represented by Yosemite Falls.

18. (*a*) Explain what a flood plain is and how it is formed. (*b*) Explain what meanders are and how they develop.

19. With the aid of diagrams, explain how a meander forms a cutoff and an oxbow lake. What happens to oxbow lakes?

20. (*a*) Explain the origin of a water gap. (*b*) Define a wind gap and explain its origin.

21. (*a*) What is alluvium? (*b*) Why does a river deposit its load? (*c*) State three characteristics of alluvial deposits.

22. (*a*) Describe the origin of a delta and the conditions that favor its formation. (*b*) What are distributaries? (*c*) Name and locate three great deltas.

23. (*a*) Describe the origin, shape, composition, and occurrence of alluvial fans. (*b*) How do fans differ from deltas? (*c*) What is a piedmont alluvial plain?

24. (*a*) Explain how deposition takes place on the flood plain. (*b*) Explain the origin of natural levees. (*c*) What are back swamps? (*d*) What is a yazoo stream? (*e*) Why are artificial levees built? How?

25. Briefly describe the idea in physiography that land forms have a life history.

26–28. Make a table summarizing the characteristics of young, mature, and old rivers under these headings: (*a*) slope (*b*) speed (*c*) course (*d*) tributaries (*e*) principal work (*f*) valley cross section (*g*) flood plain (*h*) divides (*i*) special features (*j*) examples.

29. What is a peneplane? Why are old rivers so hard to find? What evidence is there that rivers ever reach old age?

GENERAL QUESTIONS

1. Why should the Niagara River upstream from Niagara Falls have less eroding power than downstream, even where it flows at equal speeds?

2. The rock layers of Niagara are not perfectly horizontal, but dip into the earth toward Niagara's source. How will continued recession change the height of Niagara Falls? Explain.

3. What will happen to the shape of Niagara Falls when the Canadian Falls recedes beyond Goat Island? Explain.

4. At Yellowstone Falls, what prevents the river from eroding deeply into the soft rock above the falls?

5. Under what conditions may a river be able to build a delta along an open sea coast?

6. Can a tributary form a delta in its main stream? Explain.

7. Alluvial fans are made of more porous sediments near the mountain than farther away. Why?

8. Why is a meandering river like the Rio Grande a very unsatisfactory boundary between the United States and Mexico?

9. Why is it wiser to purchase land on the inside bank rather than the outside bank of a meander?

10. How may a river capture its own tributary?

STUDENT ACTIVITIES

1. Making field trips to places where stream work may be observed
2. Taking trips to museums to study physiographic models of land forms created by rivers
3. Making physiographic models of water gaps, canyons, waterfalls, flood plains, fans, deltas, etc., from clay or other materials
4. Collecting river-worn sediments
5. Observing the formation of gullies during rains and their growth by headward erosion
6. Studying topographic maps illustrating the work of rivers
7. Collecting photographs of river-made land forms

SUPPLEMENTARY TOPICS

1. The Grand Canyon and Other Canyons
2. Great Waterfalls of the World
3. Niagara Gorge
4. The Yazoo River
5. The Mississippi Delta
6. Shifting of the Mouth of the Hoang-Ho River of China
7. Other Methods of Stream Piracy
8. Natural Bridges Formed by Rivers
9. Description of a Water Gap

TOPOGRAPHIC SHEETS

1. *Canyon:* Bright Angel, Arizona
2. *Waterfalls:* Niagara, Ont. 30M/3E
3. *Alluvial fans:* Cucamonga, California
4. *Meanders and flood plain:* Alexander, Man. 62F/16W
5. *Natural levees and flood plain:* Donaldsonville, Louisiana
6. *Young valley:* Chéticamp R., N.S. 11K/10W
7. *Mature valley:* St. Thomas, Ont. 40I/14W
8. *Water gaps:* Harrisburg, Pennsylvania

SUGGESTIONS FOR FURTHER READING

Great Rivers of the World, by W. S. Dakin. Macmillan, New York, 1948.

Earth's Grandest Rivers, by F. C. Lane. Doubleday, Garden City, New York, 1949.

(*Also see list at the end of Chapter 5.*)

Chapter 9

GLACIERS AND LAND FORMS

ORIGIN, TYPES, AND OCCURRENCE

1. What is a glacier? Imagine a steep young valley high in the Alps of Switzerland. Instead of a narrow river running in a thin stream at the bottom of this valley, you notice that the entire valley floor is covered with a thick mass of snow-clad ice. This mass of ice extends completely across the valley and hundreds of feet up the valley walls. It can be followed up the valley for miles to a source in vast fields of ice and snow just below the very highest peaks. Careful observation reveals that it is moving downhill at the rate of several feet a day. Followed down the valley, it thins out and then suddenly ends. Milky water runs out from beneath the ice and flows down the now-open valley. This broad, slow-moving, thick stream of ice is a *valley glacier*.

Imagine a great land mass in the polar latitudes of the far north or south. The climate is so cold that only snow falls. For thousands of years snows have been falling, accumulating, and changing to ice. Almost the entire land mass, thousands upon thousands of square miles of lowland, hill, valley, and mountain, is covered by a thick sheet of ice through which only the highest mountain peaks protrude. The ice is thousands of feet thick, and it moves outward from the center in all directions—north, south, east, and west—toward the sea coasts. In some places it reaches the sea through low valleys, and great chunks of ice break off to float away as icebergs. This moving sheet of ice is a *continental glacier*.

2. The line of perpetual snow. Glaciers are born in regions of perpetual snow, that is, in regions where each

Fig. 9–1. The Great Aletsch Glacier seen from Jungfraujoch in the Bernese Oberland of the Swiss Alps.

Courtesy Swiss National Travel Office

National Film Board, Canada

Fig. 9–2. Snow line in the Coast Mountains of British Columbia.

year more snow falls than melts, and some is always left over to add to the accumulations of previous years. Climates cold enough to produce such conditions may occur in any part of the world, because air temperatures grow colder with increasing height above sea level, as well as with increased distance from the Equator. Even in equatorial regions, then, perpetual snows may occur on high mountains; farther from the Equator, the mountains need not be as high; in the polar regions, perpetual snows may exist even at sea level. The lowest level to which the perpetual snows reach in summer is called the *snow line.* The snow line may also be defined as the level above which there is always snow, even in summer. A mountain that is completely covered with snow in winter, but from which the snows are all gone by summer, has no snow line.

The snow line is highest at the Equator and lowest at the poles. As climates become colder with increasing latitude (distance from the Equator), less altitude is needed to reach a snow line. The position of the snow line also varies with such factors as the total yearly snowfall and the amount of exposure to the sun. Thus no exact height can be given for each latitude. Going from the Equator through South America and North America to the North Pole, the snow line drops with increasing latitude approximately as follows: Andes Mountains at the Equator, 18,000 feet or 3½ miles; Mexico, 15,000 feet; Sierra Nevada, 13,000 feet; Rocky Mountains, 9000 feet; Ellesmere Island 3000 feet; North Pole, under 1000 feet.

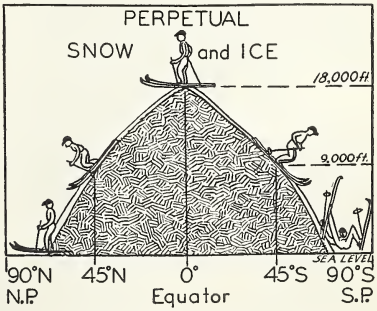


Fig. 9–3. This diagram shows the approximate height of the snow line in all latitudes from the Equator to the two Poles. The higher the latitude, the lower the snow line.

3. Birth of a glacier. Except for its bare rock cliffs, the entire mass of a mountain above the snow line is almost completely buried in its accumulated snows. Great basins and depressions below the highest peaks are filled with snows reaching hundreds of feet in thickness. In these vast *snow fields*, which in warmer climates might hold the waters of mountain lakes, the freshly fallen snows melt and freeze and become compressed until they are transformed into a rough granular icy material called *névé* (nay *vay*) which resembles the ice of old snow or of a packed snowball. With further compression the névé turns to ice, and as the weight of the entire mass increases, tongues of ice are squeezed out through the valleys into which the great snow basins open. Thus are the glaciers of the mountains born.

4. Where valley glaciers occur. While there are many types of glaciers, the two principal types are those described in Topic 1. *Valley glaciers* were first studied in the Alps and are also known as *alpine* or *mountain glaciers.* They occur in all parts of the world where mountains extend above the snow line. In other words, they occur wherever there is sufficient altitude. With the exception of Australia, every continent has mountains that reach above the snow line. The higher the mountain extends above the snow line, the larger its glaciers are likely to be.

Valley glaciers vary in length from 1 or 2 miles up to 75 miles; in width from fractions of a mile to several miles; and in thickness up to a thousand feet. Valley glaciers attain their greatest size in southern Alaska, where mountains with a snow line at 5000 feet extend to

Fig. 9–4. Snow fields, névé, and glaciers high in the Swiss Alps above the resort town of Zermatt. The glaciers reach almost to the tops of their valley walls. Note the sharpness of the divides that separate the glacial valleys.

Courtesy Swiss National Travel Office

lofty heights above 20,000 feet. Western Canada has many glaciers in the Rockies and the Coast Ranges. East of the Rockies there are no glaciers in southern Canada. Along the east coast very small glaciers are found in the mountains of northern Labrador. Large glaciers are found in Baffin, Devon and Ellesmere islands, but none exists in the western Arctic islands.

Notable systems of valley glaciers also occur in the Alps and the Caucasus Mountains of Europe, the Andes of South America, and the giant Himalayas of Asia, the highest mountains in the world.

5. Where continental glaciers occur. *Ice sheets* or *continental glaciers* owe their existence to latitudes so high that the snow line is nearly at sea level, and all or nearly all of an entire region is above the snow line. The only two great land masses of the world that lie in such high latitudes are Greenland in the north polar region and Antarctica in the south polar region. The Greenland ice sheet, more than 700,000 square miles in area and thousands of feet thick, covers all of Greenland except a small strip of its coastal lands. The Antarctic ice sheet, covering a far larger land mass, is millions of square miles in area and reaches a height of 10,000 feet.

Since glaciers are formed from long-accumulated snows, they cannot form over the oceans. The South Pole, being in Antarctica, is covered by the Antarctic ice sheet. The North Pole, on the other hand, is not in Greenland but in the Arctic Ocean, and is therefore not covered by a glacier.

GLACIER MOVEMENT

6. How glaciers move. Gravity causes glaciers to move, but the exact manner in which these great masses of ice do so is not yet known. Some scientists believe that glaciers slide, others that they roll grain over grain, and still others that they flow under pressure like pitch. But whatever the explanation of their motion, certain characteristics have been observed. Friction with bedrock slows the motion of ice just as it does that of running water. Consequently a glacier moves more slowly at the bottom than at the top, more slowly at its sides than in its center, and more slowly over a rough bed than a steep one. Like running water, a glacier moves faster over a steep, straight course than over a gentle, winding one. Just as greater volume of water causes greater velocity, so does greater thickness of ice. Glaciers move faster in warm weather than in cold weather.

7. How far glaciers move. Moving out of their feeding grounds in the upper snow fields, glaciers flow slowly downhill. Here and there tributary glaciers, like tributary rivers, move in from side valleys to add bulk to the main ice stream. In general, however, the glacier shrinks steadily because of melting and evaporation as it moves into lower,

Fig. 9–5. A continental glacier covers all of the land area except the very highest mountain tops. This photo shows a camp of the Victor Arctic Research Expedition to Greenland in 1948.

Courtesy French Embassy Information Division

warmer altitudes. *As long as the ice moves faster than it melts, it continues to advance.* Most glaciers extend miles beyond the snow line to a level thousands of feet below it. Finally the glacier reaches its lowest limit at the level *where the ice melts as fast as it moves.* Here the glacier comes to an end. In Switzerland it is not at all unusual for this *glacier front* or *ice front,* as it is sometimes called, to reach almost into the streets of the Alpine villages.

The glacier itself always moves forward, but as long as the rates of movement and melting are equal, the glacier front will appear to be *stationary.* After a winter of heavy snows the glacier may move faster than it melts, advancing beyond its usual limit. In very warm summers, on the other hand, it may melt faster than it moves, and the ice front will recede or appear to move back.

In regions like northeastern Canada, where the snow line is close to sea level, many glaciers reach the sea. Even at sea level they do not melt as fast as they move, and as they extend into the water, great blocks break off to become icebergs. In Antarctica, where the snow line is at sea level, the ice sheet reaches the coast line everywhere.

8. When glaciers crack up. Like any ice, glacial ice is brittle and likely to form cracks under strain. These cracks, called *crevasses* may extend across the whole width of a glacier in gaps many feet wide and perhaps a hundred feet deep, closing up under pressure as they approach the bottom of the ice. Crevasses form across the width of a glacier when it moves over steeper slopes, in much the same way as the water of a river breaks over rapids and falls. Cre-

Fig. 9–6. A small ice cap and glaciers, Ellesmere Island, Northwest Territories.

National Film Board, Canada

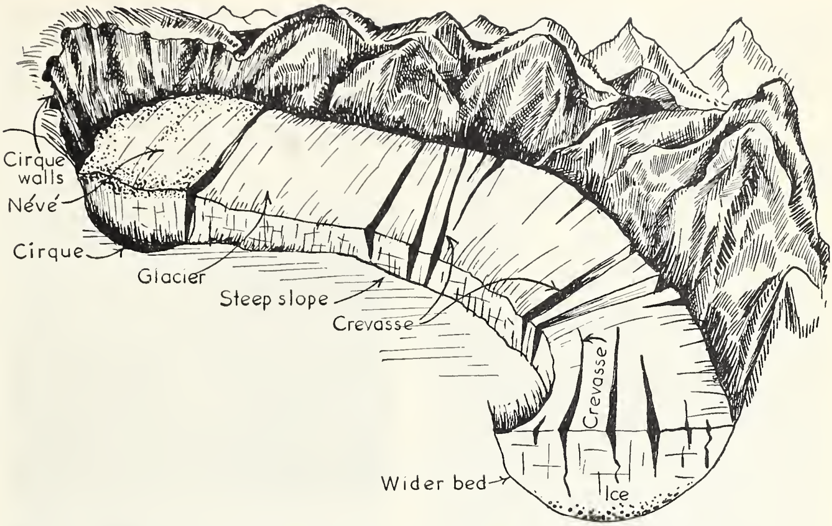


Fig. 9–7. Sketch showing the development of crevasses in an alpine glacier.

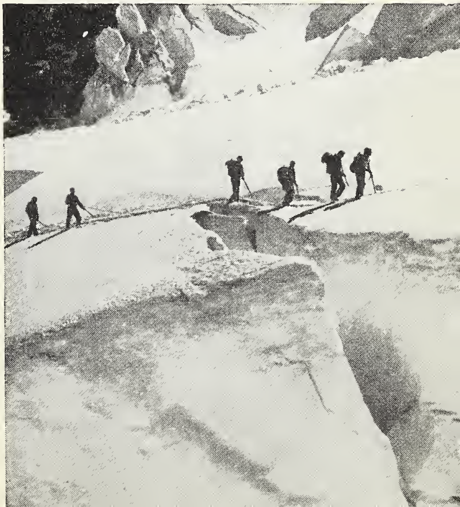
vasses may also form along the sides of a glacier because of the more rapid motion of the center ice, while lengthwise crevasses may form when a glacier spreads out like an alluvial fan at the open end of a steep mountain valley.

9. Glaciers transport loose rock. Like rivers, glaciers remove loose rock from the valleys through which they move. All rock material carried by a glacier is called *moraine* (moh *rayn*). There seems to be almost no limit to the size and amount of material carried by a glacier. Particles ranging in size from fine rock dust to giant boulders are picked up by the glacier itself from its valley floor, while additional material is brought to it by tributary glaciers, or falls into it from the valley walls.

Large accumulations of rock fragments, frozen into the bottom of the glacier, are known as the *ground moraine.* The two long lines of rock fragments that pile up along the valley margins of the glacier are called *lateral moraines.* When two glaciers merge to form a single larger glacier, their inside lateral moraines run together in the interior of the new glacier to form a *medial moraine.* At the ice front, rock fragments brought forward by the gla-

Fig. 9–8. Mountain climbers proceed cautiously past a crevasse in Coleman Glacier on Mount Baker, Mount Baker National Forest, Washington.

U.S. Forest Service



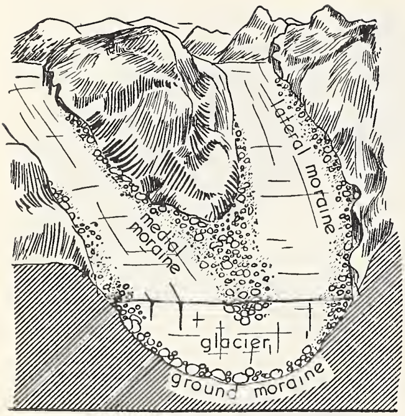


Fig. 9–9. Sketch showing the origin and position of ground, lateral, and medial moraines.

cier's motion accumulate as the ice melts, and pile up as a *terminal moraine*, which may grow very large if the ice front is stationary for a long time.

10. Glaciers leave their mark. Glaciers, like winds and rivers, erode the bedrock largely through the use of rock fragments as cutting tools. These fragments, frozen into the bottom ice and subjected to enormous pressure, are dragged over the bedrock by the forward movement of the glacier. Particles of fine sand, acting like sandpaper, *smooth and polish* the bedrock. Coarse sand, pebbles, and sharp boulders leave long parallel scratches called *striae* (*stry* ee) which plainly show the direction of ice movement. If the bedrock

Fig. 9–10. The dark ribbon of rock material winding through the ice is a medial moraine in the Fiescher Glacier of the Swiss Alps.

Courtesy Swiss National Travel Office

J. F. Wright, Geological Survey of Canada

Fig. 9–11. A striated, grooved and polished, glaciated surface, the Thousand Islands, near Brockville, Ontario.

U.S. Geological Survey

Fig. 9–12. A glacial boulder flattened, polished, and striated from being dragged under the ice. Note the parallel position of the striations or scratches.

is especially soft, pebbles and small boulders may dig in so deeply as to leave long parallel *grooves*. The pebbles and boulders show signs of wear too, becoming flattened by the dragging and scratched by the harder minerals in the bedrock.

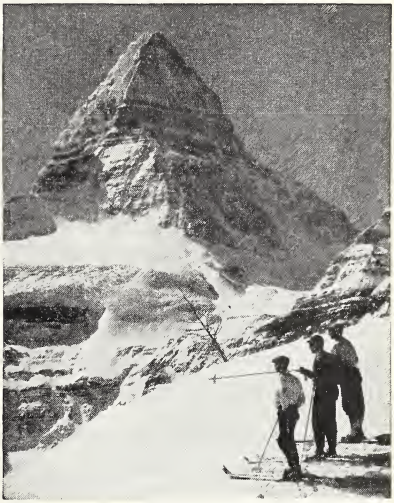
11. Shaping the bedrock. Glacial erosion shapes the bedrock into many new forms. Outcrops of bedrock become smoothened and polished on the side from which the glacier came, while the lee side is often left steep and rough by glacial removal of loose blocks of rock. These outcrops are called *roches moutonnées* (rosh moo toe *nay*) meaning *sheep rocks*, because of their resemblance to resting sheep. Potholes, like those formed in river beds, are ground out beneath glaciers by water falling through glacial crevasses.

U.S. Geological Survey

Fig. 9–13. Roches moutonnées near Fresno, California, show the smooth polished surfaces produced by the scouring action of a glacier.

Frost action and glacial erosion combine to wear back the rock walls of the mountain peak against which the head of the glacier rests, and to transform them into towering cliffs. The enlarged, deepened basin thus formed at the head of the glacial valley is called a *cirque* (serk). Cirques are often described as "natural amphitheaters" or bowls. The action by which cirques are formed is similar to the headward erosion that takes place at the source of a river.

When two cirques are formed on opposite sides of a peak, the divide between them may become extremely narrow and sharp. It is then called an *arête* (ah *ret*), or *knife-edge* ridge. When three cirques cut into the same mountain peak, it may be cut away so much that a spectacular pyramid-shaped peak, rising almost to a needle-point, is all that is left. Such peaks are called *matterhorns*, after the famous Matterhorn in Switzerland.



Courtesy Canadian Pacific Railway

Fig. 9–14. The two great basins at the foot of Mount Assiniboine are cirques. Mount Assiniboine is known as the "Matterhorn" of the Canadian Rockies.

12. Glacial valleys can be recognized. Unlike a river, a valley glacier is in contact with the entire valley floor and a large part of the valley walls, and is therefore able to erode them directly.

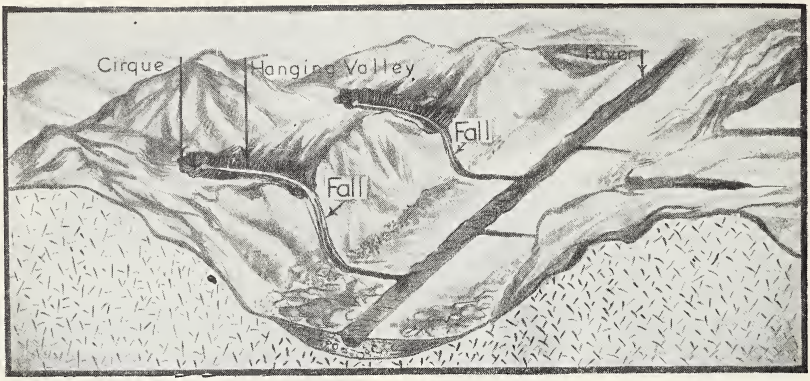
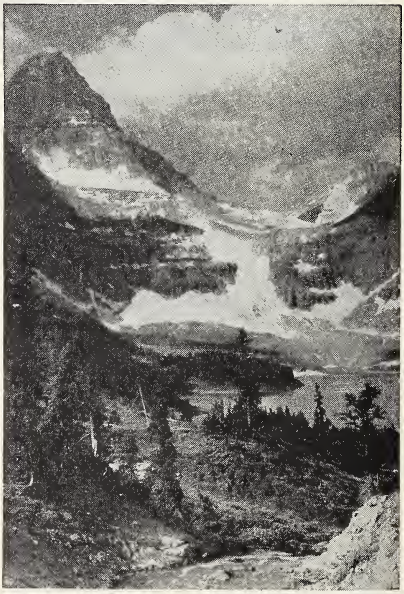


Fig. 9–15. Sketch showing a main glacial trough and its hanging tributary valleys with their waterfalls and cirques.

Glacial erosion transforms V-shaped river valleys into valleys with flat floors and nearly vertical sides. These glacial valleys are U-shaped up to the point on the valley walls reached by the glacier. They are called *glacial troughs.* The glacier also deepens the valley, particularly in its upper portions where the ice is thickest.

Main valley glaciers are usually much thicker than their tributary glaciers and erode their valleys much more powerfully. In regions from which warmer climates have caused glaciers to disappear, the main valleys are found to be eroded to much greater depths than their tributary valleys, which end abruptly high on the cliff-like walls of the main glacial trough. The tributary valleys are called *hanging valleys,* and the rivers which now run in them form *hanging valley waterfalls* as they plunge over the cliffs into the main river below. Glacial troughs, hanging valleys, and hanging valley falls are common in all glaciated mountains. The largest of all hanging valley falls is Yosemite Falls in Yosemite National Park, California.

13. Alpine topography. *Alpine topography* indicates the features resulting from erosion of a mountain region by valley glaciers. Such topography includes the many features described earlier and is quite different from the to-



Canadian Pacific Railway

Fig. 9–16. A hanging valley below Mount Assiniboine in the Rocky Mountains.

pography of mountains eroded only by rivers. In particular, the steep walls of glacial troughs and cirques produce knife-edge ridges and matterhorn peaks that cannot be seen in river-eroded regions. The entire alpine scene, even if its snows and glaciers have long since disappeared, is one of sharpness and angularity that is in marked contrast to the rounded slopes of water-worn regions. Alpine topography can be seen not only where alpine glaciers exist today, but also in regions subjected to glacial erosion within recent geological time.

14. What continental glaciers do. Like alpine glaciers, continental glaciers remove mantle rock, smooth and striate and groove bedrock, form roches moutonnées, and grind out potholes. But their erosion of mountain regions differs from that of alpine glaciers in several respects. A continental glacier deepens and widens only those valleys that run parallel to its direction of motion. Since it covers even the mountain tops, it grinds down the peaks and leaves them polished and rounded, rather than sharpened as in alpine regions. In general, the topography of a region eroded by a continental glacier is considerably gentler than alpine topography.

DIRECT DEPOSITS BY GLACIERS

15. How was it deposited? The rock material carried by glaciers, like that carried by winds and rivers, is eventually deposited on the land. Changes in velocity have practically no effect on the carrying power of a glacier, and its deposits are made almost entirely as a result of its melting. All glacial deposits are known as *drift*. This term originated in the days when they were not known to be caused by glaciers, but were thought to have been left by a great flood like that of Biblical times.

Drift is divided into two classes. Deposits made by the glacier itself when it melts are called *direct glacial deposits or till*. All *till* deposits are *unstratified*, because the morainal materials simply pile up on top of each other as the ice melts. Deposits made by streams of water that run underneath the ice or out of the ice front are called *indirect glacial deposits* or *fluvio-glacial* (flowing glacial) deposits. Since these are made by running water, they are *stratified* like river deposits, though less perfectly. Unlike till, these deposits never contain boulders.

16. Glaciers leave moraines. When a glacier melts, it leaves its moraines in nearly the same positions as they occupied in the glacier. The *ground moraine* forms a thin, fairly even deposit over the entire area occupied by the ice. *Lateral and medial moraines* form ridges running approximately in the direction of glacial movement. The *terminal moraine*, usually the thickest and most conspicuous of the moraines, forms a

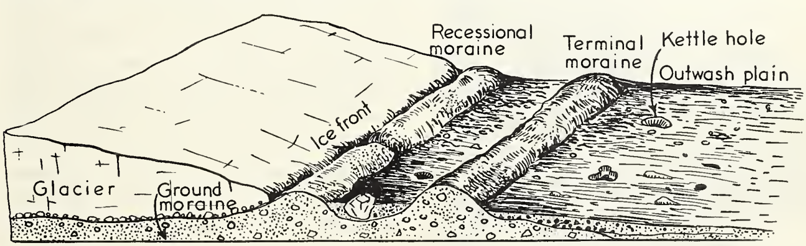


Fig. 9–17. Sketch of a glacier with its moraines and its outwash plain.

ridge all along the ice front, marking the farthest position reached by the advance of the glacier. The longer the ice front stays in one place, the larger the terminal moraine becomes. When a receding ice front stops in new positions for any length of time, new "terminal" moraines are formed behind the principal one. These moraines are called *recessional moraines.*

Since even a "stationary" ice front moves back and forth slightly with the seasons, terminal moraine deposits are spread over a fairly broad belt in front of a glacier. For this reason, as well as because no two parts of the ice front deposit exactly the same amount of material, terminal and recessional moraines are likely to consist of a series of irregular hills and hollows rather than a single straight ridge. Terminal moraines of continental glaciers may be hundreds of miles long, miles wide, and hundreds of feet high. A moraine forms the hilly country between Trenton and Aurora in south-central Ontario. Long moraines are found in the Prairies.

The materials of the moraines are boulders, pebbles, sands, and clays,

Fig. 9–18. This "glacial table" is formed because the huge rock boulder protects the glacial ice beneath it from melting. When this boulder finally comes to rest on the bedrock at the ice front, it may become an erratic.

Courtesy Swiss National Travel Office

mixed in widely varying proportions, and always unstratified. Large glacial boulders are called *erratics,* indicating that they have wandered from their original locations and are different from the underlying bedrock. In regions of continental glaciation, erratics weighing many tons may be found resting on mountain tops hundreds of miles from their place of origin. The melting of glaciers often lets down giant erratics so gently that they remain delicately balanced in unstable positions, where they are known as *perched boulders* or *rocking stones.*

17. Canoe-shaped hills called drumlins. *Drumlins* are long, smooth, oval-shaped hills composed of till. They usually occur in groups in which all the hills are more or less parallel to each other and pointing in the direction of glacier movement. The hills have the shapes of overturned canoes, with their steep ends facing the direction from which the glacier came. Drumlins usually vary in length from a quarter-mile to a half-mile, and in height from 50 to 100 feet. Occasional drumlins are longer and higher.

Drumlins occur relatively seldom in regions of continental glaciation. Their origin is not definitely known. According to one theory, they are formed when an advancing glacier overruns previous moraine deposits, sweeping the ground moraine into long strips or ridges. Another theory suggests that they were formed by deposition of sediment in lengthwise glacial crevasses. Large groups of drumlins occur in southeastern Wisconsin, in New York State south of Lake Ontario (between Syracuse and Rochester), in southern Ontario north of Lake Ontario, and in great numbers in the Northwest Territories west of Hudson Bay. Drumlins also

Royal Canadian Air Force

Fig. 9–19. A partly submerged drumlin at Chester, Nova Scotia, suggesting the shape of an overturned boat.

occur in Ireland, where the name *drumlin*, or *little hill*, originates.

FLUVIO-GLACIAL OR INDIRECT DEPOSITS

18. Plains that are washed out. The water from the melted ice of a glacier pours out at the ice front, over and through the terminal moraine, in streams carrying all sizes of sediment except large boulders. Dropping the coarse gravels and sands first, while carrying the finer silts and clays much farther, these streams form gently sloping deposits that may extend for miles beyond the terminal moraine. The deposits resemble alluvial fans, and in front of large glaciers they merge to form broad, relatively flat areas called *outwash plains*. Like terminal moraines, outwash plains may parallel the ice front for hundreds of miles. A great outwash plain on Long Island runs southward from the terminal moraine to the sea, forming the level, sandy southern half of Long Island for its entire length of almost 140 miles (see Figure 9–17).

Where only a single stream emerges from a small valley glacier, it may drop its deposits for miles along the valley floor down which it runs. Such a deposit of glacial sediment is called a *valley train*. In both outwash plains and valley trains, the sediments are stratified, since they are deposited by running water.

19. Winding hills called eskers. Much of the water of a melting glacier falls to the bottom of the ice through crevasses, forming *subglacial streams* which run in tunnels beneath the ice until they emerge at the ice front. The winding tunnels of these streams become partly filled with layer upon layer of roughly stratified sands and gravel. When the glacier disappears, the deposits slump down at the sides and are left as winding sand-and-gravel ridges called *eskers*.

Eskers resemble railroad embankments in appearance, with side slopes of about 30 degrees and with fairly level, but narrow tops. The usual esker is about a mile long, and anywhere from a few yards to a few hundred feet wide at its base. However, there are some unusual eskers over a hundred miles long. The height of an esker is in proportion

M. E. Wilson, Geological Survey of Canada

Fig. 9–20. A large esker in Hungerford Township, Ontario, winds from the right background to the foreground of the photograph.

to its width, rarely exceeding a hundred feet. In Canada, short eskers are found in most southern parts of the country including southern Ontario and the Eastern Townships of Quebec. They are however most numerous in northern Canada where they may exceed 100 miles in length. Eskers often run in a direction roughly parallel to the direction of ice movement at the end of the glaciation.

20. Kames and kettles. *Kames* (kayms) are small cone-shaped hills of stratified sand and gravel. They are formed when streams from the surface of the glacier deposit their sediments in heaps at the ice-front margins of the glacier or at the bottom of circular "wells" (depressions) in the glacier itself. Kames may occur as parts of terminal moraines, or in the areas between the moraines and the level outwash plains.

Where kames occur in groups, the depressions between them are called *kettles.* The term *kettle* or *kettle hole* is also applied to circular depressions found on terminal moraines and outwash plains. Kettles are formed when moraine or outwash deposits surround and bury large blocks of ice left by slight glacial recession. When the blocks melt, they leave the kettle holes (see Figure 9–17).

21. Lakes made by glaciers. Glaciation of a region usually results in the formation of many new basins or depressions in the land surface. If these basins are permanently filled with water, they form lakes, ponds, or swamps, depending on how large and deep they are. Three important types of lakes resulting from glaciation are *cirque lakes, kettle lakes,* and *moraine-dammed lakes.*

Cirque lakes are formed when water fills the rock-floored cirque basins left by alpine glaciers that have disappeared. Alpine glaciers may scoop out additional rock basins in soft rock areas below the cirques. Lakes in such basins are called *rock-basin lakes.* Cirque lakes and rock-basin lakes, also called *tarns,* are fairly

Courtesy Canadian Pacific Railway

Fig. 9–21. Rock Isle Lake, a rock-basin lake of glacial origin. Sunshine Valley near Banff, Alberta in the Canadian Rockies.

common in glaciated mountains such as the Rockies and the Alps.

Kettle lakes form in large numbers in the kettle holes of moraines and outwash plains. Small kettle holes may contain ponds or swamps. Lakes, ponds, and swamps of this type are common in Alberta and Saskatchewan. Small ponds may be found in the moraines north of Toronto and southwestern Ontario. They are very numerous in northern Canada. The town of Lake Success, former site of the United Nations Security Council, is named after a nearby kettle lake.

Moraine-dammed lakes are formed where river valleys are blocked by glacial moraines that prevent the flow of the river. In rising to the height of the moraine dam, the river floods its valley to form a long, usually narrow lake. Many lakes originated in this way. Rice and Scugog lakes in southern Ontario, Lake Memphramagog in Quebec and Lesser Slave Lake in northern Alberta, are specific examples.

In many cases, lakes were formed by a combination of glacial erosion and deposition which scoured out river valleys before damming them. The Finger Lakes of central New York State—Lakes Seneca, Cayuga, Canandaigua, and others—were formed by glacial deposits that dammed up the northern ends of parallel north-south river valleys. Many of their former tributary valleys were converted into hanging valleys. These lakes are called *finger lakes* because of their long narrow shape. The Great Lakes have a more complicated history, but they, too, occupy river valleys which were deepened and dammed by glaciers.

THE ICE AGE

22. How it happened. A million years ago it was as cold in much of North America and northern Europe as it is today in Greenland. Great ice sheets formed over the Western Cordillera, the northeast of Canada, and Scandinavia. In North America the ice sheets grew in size until the whole of Canada (except part of the Yukon) was covered, and

Fig. 9–22. Map showing in white the areas covered by the continental glaciers of North America during the Ice Age. Note the uncovered Driftless Area in Wisconsin, and the two great centers from which the ice originated.

the ice extended south into the United States as far as the Missouri and Ohio rivers, and halfway across Long Island, N.Y. In Europe the ice sheet expanded from the highlands of Scandinavia and linked with smaller ice caps in the British Isles. At its maximum extent the southern boundary of the ice lay from southern Ireland across southern England, northern France, and central Germany to the Ukraine.

In North America the Cordillera ice covered the western mountains of Canada and sent large glaciers down into the Pacific Ocean. This ice met the ice from the east, along the foothills of the Rockies in western Alberta. For the greater part of the glaciation, the ice over eastern North America flowed north and south from an ice divide which lay east-west across Canada. At the close of the glaciation the main ice sheet broke into smaller ice caps which occupied northern Quebec, Hudson Bay and parts of the Northwest Territories.

Along its southern edge, the ice often moved as separate lobes. In Wisconsin the lobes failed to meet, and left a *Driftless Area* about the size of New Jersey.

The ice sheets advanced and receded many times during the Ice Age as the climate changed from cold to warm and back again. The last recession took place perhaps 11,000 years ago, and many scientists believe that we are now in a warm or *interglacial period* which will be followed by a return of the ice sheets.

23. Evidence of the Ice Age. Proof of the occurrence of an Ice Age is supplied by the many glacial features described in the preceding paragraphs. The southernmost extent of the ice sheets is marked by their terminal moraines. One of the most notable of these is the Long Island moraine that extends almost 140 miles from Brooklyn to Montauk Point. Terminal moraines may also be seen running from New Jersey through Pennsylvania, Ohio, Indiana, Illinois, and westward. South of the terminal moraine, outwash plains often occur.

Large areas of the United States and Canada north of the moraines is covered by a mantle of transported drift or glacial material. Glacial erratics, conspicuously different from the bedrock on which they rest, are so numerous in the ground moraine soils of areas adjacent to the Canadian Shield as to make cultivation exceedingly difficult. Exposed bedrock is *striated, grooved,* and *polished,* even on mountain tops; north-south valleys are shaped into glacial troughs and east-west valleys are

partly filled with drift. Kames, eskers, drumlins, and recessional moraines are found in many parts of the glaciated area. Numerous glacial lakes and swamps dot the landscape, greatly contrasting with the general absence of lakes in unglaciated areas south of the terminal moraine. Rivers, blocked by glacial deposits and turned into new channels, have entered upon a new cycle of erosion and are young again. Some, like the Niagara, have dug out gorges in the short period since the close of the Ice Age.

In the Rockies and the Sierra Nevadas, the existence of much larger glaciers during the Ice Age is shown by glacial troughs and hanging valleys, by morainal deposits far down the valleys beyond any present ice front, and by glacial markings high upon the valley walls.

HAVE YOU LEARNED THESE?

Meanings of: snow line, névé, crevasse, moraine, drift, drumlin, erratic, kame, kettle, esker, outwash plain, striae, grooves

Diagrams of: moraines and outwash plain

Origin of: valley and continental glaciers, icebergs, crevasses, moraines, striae, grooves, polished rock, potholes, roches moutonnées, arêtes, cirques, matterhorns, glacial trough, hanging valleys and falls, terminal and recessional moraines, drumlins, kames, kettles, eskers, outwash plains, valley trains, Driftless Area, glacial lakes

Explanations of: the snow line and its position; the advance, recession, and standing of glaciers; glacier motion; the Ice Age, its extent, and its duration; evidences of Ice Age glaciation

Occurrences of: all glacial features for which examples have been given in the text

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. In your own words, describe: (*a*) a valley glacier, (*b*) a continental glacier.

2. (*a*) Define the snow line and explain its meaning. (*b*) Explain how the snow line varies with latitude, and give examples.

3. Describe the origin of a mountain glacier. What is névé?

4. (*a*) Where are valley glaciers generally found? (*b*) How large are valley glaciers? (*c*) Describe the occurrence of valley glaciers in North America and elsewhere.

5. (*a*) Where do continental glaciers occur? (*b*) Describe the world's two continental glaciers. (*c*) Are the poles covered by glaciers? Explain.

6. Describe the characteristics of glacier motion.

7. (*a*) Why do glaciers reach beyond the snow line? (*b*) What determines how far a glacier can go? (*c*) Explain when the ice front is stationary, advancing, or retreating. (*d*) When do glaciers reach the sea coast? (*e*) How are icebergs formed?

8. Describe crevasses, and explain their origin.

9. (*a*) Describe the kind, amount, and source of material carried by a glacier. (*b*) Explain what ground, lateral, medial, and terminal moraines are.

10. Explain the origin of polished, striated, and grooved bedrock and boulders.

11. Describe the origin of roches moutonnées, potholes, cirques, arêtes, and matterhorns.

12. Describe the shape and origin of glacial troughs, hanging valleys, and hanging valley waterfalls.

13. Explain what is meant by alpine topography.

14. How does erosion by a continental glacier differ from that done by alpine glaciers?

15. (*a*) Explain the words drift, till, and fluvio-glacial. (*b*) How do till deposits differ from fluvio-glacial deposits?

16. (*a*) Describe the appearance of the moraines of a glacier after they are deposited by the glacier. (*b*) What are recessional moraines? (*c*) Why are terminal moraines usually broad and irregularly hilly? Describe one example. (*d*) What are moraines made of? (*e*) Describe erratics and rocking stones.

17. Describe the shape, size, possible origin, and occurrence of drumlins.

18. (*a*) Describe the origin and structure of an outwash plain. Give an example. (*b*) How is a valley train formed?

19. Describe the origin, appearance, and occurrence of eskers.

20. (*a*) What are kames? How are they formed? (*b*) What are kettles or kettle holes? How are they formed?

21. (*a*) Name and describe three important types of lakes resulting from glaciation. Give examples. (*b*) What part did glaciers play in the origin of the Finger Lakes? the Great Lakes?

22. (*a*) Describe the origin, centers of accumulation, and extent of the ice sheets in North America during the Ice Age. (*b*) How long did the Ice Age last? Was it continuous? Explain. (*c*) What is the Driftless Area?

23. Classify the evidences of glaciation given in Topic 23, using the two headings of erosion and deposition.

GENERAL QUESTIONS

1. How should the total yearly snowfall and the direction in which a mountainside faces affect the position of the snow line?

2. Give two reasons why glaciers in the Canadian Rockies should be larger than those in the American Rockies.

3. Name five mountain regions in the United States which have no glaciers.

4. Why should glaciers move faster in warm weather than in cold weather?

5. Can a glacier have more than one medial moraine? Explain.

6. Why should striae and grooves made thousands of years ago still be visible?

7. Many eskers go up and down hills. How is that possible?

8. Moraine-dammed lakes often have many irregular inlets and bays. Why?

9. How do scientists know where the centers of accumulation were during the Ice Age?

10. How did scientists identify the Driftless Area of Wisconsin?

11. After the main ice sheet disappeared from the lowlands of southern Quebec, small glaciers existed for a time in the uplands. What evidence would show this?

12. Summarize the features produced by glacial erosion.

13. List the direct and indirect deposits of continental glaciers. Which ones are unlikely to be formed by alpine glaciers?

STUDENT ACTIVITIES

1. Taking field trips to observe glacial features

2. Studying topographic maps of glacial features

3. Collecting pictures of glacial features

4. Collecting glacial pebbles and samples of glacial soils

SUPPLEMENTARY TOPICS

1. Piedmont Glaciers, Hanging Glaciers, and Ice Caps
2. The Greenland Ice Cap
3. The Antarctic Ice Cap

TOPOGRAPHIC SHEETS

Icefield: Tulsequah, B.C. 10 4/K (1:250,000)

Drumlins and Moraine: Trenton, Ont. 31C/4E

Esker: Coaticook, Que. 21E/4W

See list of suggestions for further reading at the end of Chapter 5.

Chapter 10

EARTH MOVEMENTS AND EARTHQUAKES

1. Diastrophism moves the solid crust. Early in this text it was pointed out that the destructional forces of weathering and erosion would long ago have worn the continents down to sea level had it not been for diastrophism and vulcanism. How has diastrophism operated to rebuild the continents?

Diastrophism is the movement of the earth's solid rock crust. It includes movements too slow to notice without the most careful measurement and the sudden spectacular movements which result in widely felt and destructive earthquakes. What evidence do we have that such movements take place?

2. Evidence of earth movement from the past. It is possible to prove that portions of the earth's crust have been *elevated* by the presence of marine fossils (fossils of sea animals and plants) in sedimentary rocks that are hundreds or even thousands of feet above sea level today. Other evidence is the *raised beaches, sea caves,* and other shore features that in some parts of the world are found a thousand feet higher than the ocean that produced them ages ago (see Figure 10–1).

There is also evidence that portions of the earth have been lowered or *depressed.* Studies of the ocean floor off the coasts of the United States show the presence of *submarine (undersea) canyons* which prove to be the continuation of river valleys still on the land. These canyons could only have been formed when the continental shelf, now under water, was once part of the continent itself. Their presence under water today is proof that the continent sank hundreds of feet since the days of their formation by running water. One of the greatest of these canyons is that which extends eastward a hundred miles from the mouth of the Hudson River at New York City.

3. Evidence of earth movement from modern times. The slow rise and fall of the land have been measured by man since the beginning of recorded history. Scientists have records that show a rise of certain coastal areas in Sweden, amounting to about 7 feet in the last 200 years. Going back further, it is found that docks and buildings erected along the sea by ancient Mediterranean peoples show a rise or fall exceeding 20 feet in places. One of the most interesting evidences of recent sinking of the land is the famous drowned forest on the Dogger Banks.

U.S. Geological Survey

Fig. 10–1. A sea cave raised high above the sea level at which it was formed on the California coast thousands of years ago.

These Banks, once a great island almost as large as all of Denmark, now lie submerged below 60 feet of water in the middle of the North Sea.

Sudden movements of the land have occurred in many parts of the earth within recent times and are always associated with earthquakes. Perhaps the greatest of such movements occurred in the Yakutat Bay region of Alaska during

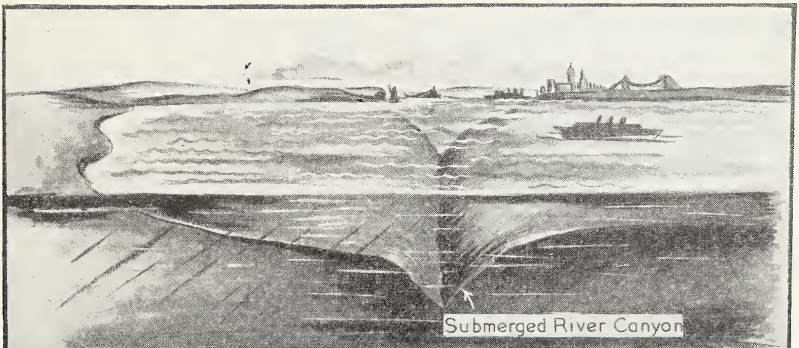


Fig. 10–2. Sketch showing the underwater appearance of a submarine canyon such as that of the Hudson River, which extends outward from New York City into the Atlantic Ocean.

the earthquake of 1899, when some parts of the coast were raised 47 feet while other parts were being lowered almost as much.

4. Changes in sea level. Coastal regions may be covered or uncovered by changes in the level of the sea, as well as by their own sinking or rising. Such changes, however, would affect all the coasts of the world at the same time. Changes in the level of the sea have probably occurred in past ages for at least three different reasons: (1) During the great Ice Ages, water that evaporated from the ocean fell and accumulated on the lands as snow. This reduced the size of the ocean and lowered its level. At the end of Ice Ages, the return of the water to the ocean raised its level. (2) Sediment deposited on the continental shelf caused the sea to rise. (3) Sinking of the sea floor caused a drop in sea level; rising of the sea floor caused a rise in sea level.

5. Submergence and emergence. In discussing the origin of land forms, physiographers often refer to their submergence and emergence. *Submergence* of a land form means that the land form becomes covered, wholly or in part, by water. This is caused by the rise of the water, by the sinking of the land, or by both events. *Emergence* of a land form means that it becomes uncovered, entirely or partly, by water. This is also caused by a fall of the water level, by a rise of the land, or by both events.

6. Cause of diastrophism. Scientists are not certain why diastrophism occurs. One belief is that a wrinkling of the outer crust occurs as the interior of the earth cools and shrinks. Another explanation is based on the idea that sediments deposited on the continental shelves reduce the weight of the continents and increase the weight of the ocean floor. From time to time the ocean floor sinks, compressing the plastic rock at the interior of the earth and making it press upward against the continents. The result is an uplift of the continents. This explanation is known as the theory of *isostasy* (eye *soss* ta si), or "equal weight." The fact that crustal movements frequently take place along the ocean margins of the continents and the fact that great mountain ranges surround the Pacific Ocean are regarded as support for the theory of isostasy.

7. Diastrophism and rock structures. Diastrophism can affect the structure of the rocks in various ways. Acting slowly on a region of horizontally stratified rocks, diastrophism may (1) raise the area without disturbing the horizontal

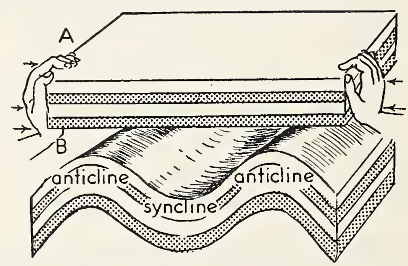


Fig. 10–3. Lateral pressure folds rock layers into anticlines and synclines. Anticlines are upfolds of rock. Synclines are downfolds.

rock structure; (2) tilt the area so that one end is higher than the other and the rock layers are not horizontal; (3) crumple the area by lateral (sidewise) pressure, causing the rock layers to become *folded* into upfolds called *anticlines* and downfolds called *synclines* (see Figures 10–3 and 10–4).

Acting suddenly, diastrophism may split the bedrock along more or less

Fig. 10–4. Anticlines and synclines in bedrock.

vertical surfaces that extend deep into the crust. Along these surfaces, called *fault planes,* great masses of the bedrock may slide vertically or horizontally in movements called *faulting.* In *vertical faulting,* entire blocks of rock may be raised evenly, keeping their rock layers horizontal, or blocks of rock may be raised higher at one end than the other, leaving the rock layers tilted (see Figures 10–5, 10–6, and 10–7). *Horizontal faulting* does not change the position of the rock layers.

8. Faulting and earthquakes. Faulting, the sudden slipping of great blocks of rock along fault planes, is most often

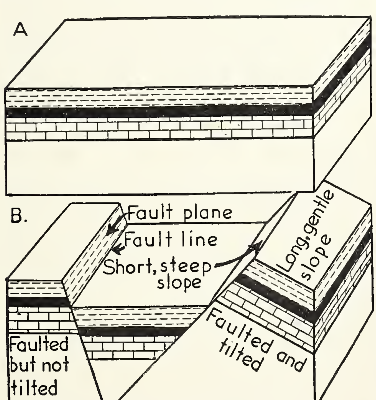


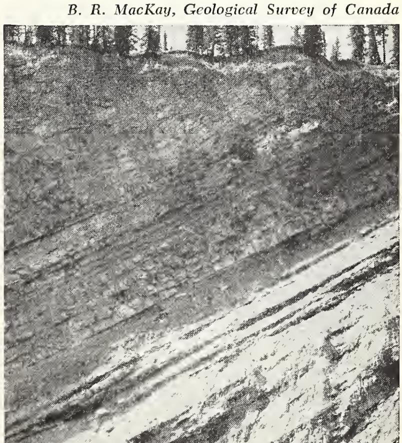
Fig. 10–5. Diagram showing faulting of bedrock. A shows the rocks before faulting; B shows them after faulting.

U.S. Geological Survey

Fig. 10–6. Vertically faulted bedrock. The dark diagonal line running across the rock layers marks the position of the fault. The rock layers have been displaced upward on the right side of the fault.

Fig. 10–7. Tilted bedrock in the foothills of the Rocky Mountains, Alberta.

B. R. MacKay, Geological Survey of Canada



explained by the *elastic rebound theory.* According to this theory, the rocks in two adjacent sections of the earth's crust are subjected to tremendous pressures *in opposite directions* for long periods of time. The pressures may be either up and down or sideways. In the immediate vicinity of the pressures the rocks may bend slowly and increasingly for many years, without any changes being noticed on the earth's surface. Then suddenly the strain may become so great that the rocks suddenly rip apart along a *fault line* that may be hundreds of miles long. Vertical pressures may lift one block many feet higher than the other; horizontal pressures may slide the two blocks in opposite directions along the fault line (see Figure 10–8).

U.S. Geological Survey

Fig. 10–8. A fault line along which horizontal movement of the crust took place in the great California earthquake of 1906.

The trembling and vibration of the solid rock *immediately after faulting* cause earthquake shocks which may be strong enough to shake an entire continent or they may be so slight that only the most sensitive instruments detect them. The shocks are strongest along the fault line, decreasing in intensity with distance from the fault. Severe shocks may last for several minutes, slight shocks but a few seconds.

Once developed, the fault plane torn in the rocks remains a zone of weakness in the crust for ages to come, for it is here that strains are most easily relieved. Erosion, too, is more rapid along fault lines than elsewhere, and valleys often develop in them.

9. Other causes of earthquakes. Faulting is the principal cause of earthquakes, and nearly all the destructive earthquakes of history originated through faulting. But earthquakes do result from other causes. Of these, the most important is *volcanic eruption.* A violent explosion of any kind, whether it be of gas, TNT, or an atom bomb, will rock the vicinity and shake the earth for varying distances. Violent explosions occur naturally in the eruptions of many volcanoes, and in some cases these have resulted in destructive earthquakes. In general, however, such earthquakes are far less extensive and less damaging than those caused by faulting. Minor earthquakes of very limited extent may be caused by landslides and cave-ins of various kinds.

10. Faulting and land forms. Repeated vertical faulting over long periods of time may be responsible for the origin of great plateaus and lofty mountains. But even a single violent movement may produce striking changes in

the landscape. Great fissures resembling the crevasses of glaciers may form in the earth. Some of these fissures close up almost immediately; others remain for years.

Small cliffs or fault scarps may form for some distance along the fault line. Rivers that flow over the scarps develop new waterfalls, while rivers flowing at the base of the scarp may form small ponds. In some earthquakes whole sections of the earth's crust may sink, forming lake basins which are soon filled with water by the streams that flow across the region. Displacement of water-bearing layers may block old springs or form new ones. Landslides may be started by earthquakes in steep hilly regions.

U.S. Geological Survey

Fig. 10–9. Fissure torn in road during the California earthquake of 1906. Here the earth was actually split open to a considerable depth.

11. Faulting in the ocean. Faulting may also take place in the rocks of the ocean basins, and deep-sea soundings show clearly the location of many fault scarps on the ocean floor. When breaks develop in the transocean cables that lie on the ocean bottom, they are usually found where the cables cross known fault scarps. Earthquakes in the ocean, whether caused by faulting or volcanic explosion, may produce gigantic waves called *tsunamis* (tsoo *na* meez). The Japanese origin of this word suggests the frequency of such sea waves on the islands of Japan. When caused by intense shocks, tsunamis may travel thousands of miles across the oceans at speeds of perhaps 500 miles per hour, and may break over low coastal areas in destructive waves rising as high as 60 feet.

12. Destruction by earthquakes. From the physiographic point of view, faulting is a constructional process. But to man, the earthquakes that follow faulting are among the most destructive of all natural occurrences. The violent shaking of the earth's crust causes flimsily constructed buildings to collapse, crushing and trapping their inhabitants within the shattered walls. An earthquake in Shensi Province, China, in 1556, is estimated to have killed nearly a million people; one in Calcutta, India, in 1737, killed 300,000 people; in 1939 an earthquake in Chile killed 50,000 people, while another in Turkey killed 23,000. In 1950 an earthquake in India took 1500 lives.

Fires (from overturned stoves, lamps, and electrical short circuits) add greatly to the loss of life and property in earthquakes, while broken water pipes and disrupted communications hinder fire fighting and rescue work. Property damage of $350,000,000 in the San Francisco earthquake of 1906 was largely the result of fire. In the great earthquake of 1923 in Japan, nearly 150,000 lives were lost and half a million buildings destroyed.

Here, too, fire played a major part in the disaster.

Tsunamis may make fearful contributions to the destructiveness of earthquakes in coastal areas. In the terrifying earthquake of 1755 in Lisbon, Portugal, a 60-foot sea wave smashed into the city immediately after the first violent shocks, and many of the 60,000 deaths in this disaster were caused by drowning.

13. Earthquakes and buildings. The ability of earthquakes to destroy buildings varies tremendously with the foundation and construction of a building. Earthquake shocks are generally more destructive in mantle rock than in bedrock, and most destructive in damp or artificially filled ground and thick alluvial deposits. Unless very well constructed, brick and stone buildings are more easily shaken apart than solid wooden structures. Steel frame and reinforced concrete buildings are highly resistant to earthquake shocks. Such buildings are also able to resist the blast of an atom bomb.

14. Detection of earthquake shocks. The *seismograph* (*syze* muh graf) is an instrument used to detect and record earthquake shocks. It is sensitive enough to detect vibrations of the bedrock that are much too slight to be felt by man. Such vibrations range from the faintest of local shocks to those produced by in-

Wide World

Fig. 10–10. This general view of the main street of the town of Imperial, California, shows how its buildings were flattened by the earthquake which struck the entire Imperial Valley of Southern California on the night of May 18, 1940.

tense earthquakes at the opposite end of the earth. The point *in the bedrock* at which an earthquake appears to originate is called its *focus*. It is usually from 5 to 14 miles below the surface. The point *on the surface* directly above the focus is called the *epicenter* (*ep* ih sen ter) of the earthquake. Here the force of the earthquake is strongest. When an earthquake occurs, vibrations spread out in all directions from the focus, traveling in waves through the bedrock.

There are several different kinds of wave motions, each having a different known speed ranging from 2.3 to 6.5 miles per second. The farther a place is from the focus of an earthquake, the longer will be the interval between the arrival of the fastest and slowest waves. From its own seismograph record, therefore, any earthquake observatory can tell *how far away* an earthquake is. (The principle involved can be illustrated by comparing a race between a bicycle and an automobile. The longer the race, the greater will be the distance and time separating the two across the finish line.) The seismograph record also indicates *how intense* an earthquake is, and *how long* it lasts.

The location of the epicenter of an earthquake can be determined from the records of three widely separated seismograph stations, of which there are about two hundred in the entire world. Using each station as a center and each station's distance from the earthquake as a radius, three circles are drawn on a map of the earth. The point where the three circles meet is at the proper distance from each center, and is therefore the epicenter of the earthquake.

Earthquake waves travel at slightly different speeds in different kinds of rock. This principle is used in modern methods of prospecting for oil. The oil

Courtesy Shell Oil Co.

Fig. 10–11. Using artificial "earthquake waves," produced by discharging explosives just below the surface, to discover oil-bearing rock layers. Dense rock layers like limestone reflect these waves more strongly than do layers of shale.

geologist sets off his own private "earthquake" by exploding a charge of dynamite in the earth above the formation he is testing for oil. By analyzing the waves that are reflected back from the rock strata underneath, it is often possible to determine whether they contain oil.

15. Distribution of earthquakes. Almost 95 per cent of all earthquakes occur in two great belts. These same belts also include most of the active volcanoes and young mountain ranges of the world. Here, in these areas where the rocks are under constant strain, diastrophism and vulcanism combine in violent movements along the most recently developed fault lines or "lines of weakness" in the earth's crust.

The *Pacific belt* forms a mountainous ring around a large part of the Pacific Ocean. It includes the Andes Mountains of South America, the coastal ranges of Central and North America, the Aleutian Islands in the North Pacific, the islands of Japan, the Philip-

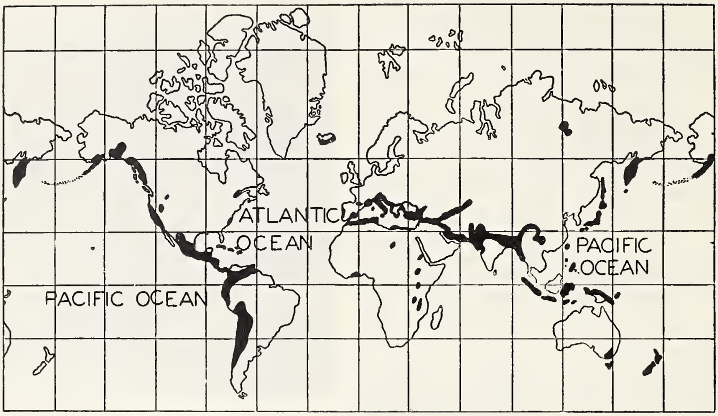


Fig. 10–12. Map showing the principal earthquake belts of the world. One belt encircles the Pacific Ocean. The other belt crosses the Mediterranean region.

pines, the East Indies, and New Zealand. The other belt, often called the *Mediterranean belt,* runs from east to west around the earth, crossing the Pacific belt in Central America and the East Indies. Going westward from Central America, it passes through the Hawaiian Islands, the East Indies, southern Asia, the Mediterranean countries, the Azores Islands, and the West Indies.

16. Major North American Earthquakes. The only part of North America that lies in a major earthquake belt is the Pacific Coast region. Most of the earthquakes in this region occur in California, particularly near San Francisco, to the west of which runs the 400-mile long fault line known as the San Andreas Rift. It was along this great fault that the earth's crust slipped in the great earthquake of 1906. Other violent quakes have occurred in California in the recent past (Santa Barbara, 1925; Long Beach, 1933; Imperial Valley, 1940) and noticeable earth tremors are felt on the average of at least once a month.

Earthquakes also occur in other parts of the continent, though they are much less frequent and generally less intense. Other western areas in which severe

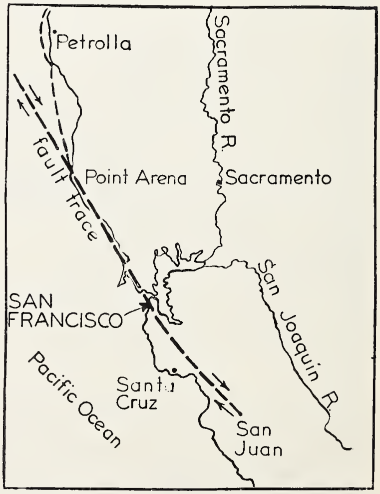


Fig. 10–13. Map of the San Andreas Rift. The broken lines show the location of the great faults along which the earth's crust moved during the California earthquakes of 1906 and other years. Arrows show the direction of movement.

shocks have occurred in recent years include British Columbia, Utah, Nevada, and Montana. In the East, there were violent earthquakes in 1811 in the lower Mississippi Valley (the New Madrid, Missouri quake) and in 1886 over an area of 2,000,000 square miles in the southeast United States. The St. Lawrence valley has experienced a number of quakes since a violent one in 1663, including one in 1925. Although they have caused property damage, none has caused loss of life. Earthquakes have also been noted under the ocean off Newfoundland, where they have broken telegraph cables, most recently in 1929.

All earthquakes in North America are caused by faulting. In the West, the faulting appears to be associated with the growth of young mountains. In east Canada, minor slipping along old fault lines is also explained as an "elastic rebound" of the rock strata. In this region of old mountains, however, the rebound is not connected with mountain growth. Instead, it is believed that the rocks are still readjusting themselves after being relieved of the weight of the great glaciers of the Ice Age, when they melted thousands of years ago.

HAVE YOU LEARNED THESE?

Meanings of: diastrophism, submergence, emergence, anticline, syncline, faulting, fault plane, fault line, fault scarp, tsunamis, seismograph, focus, epicenter

Diagrams of: anticlines and synclines; faulting of bedrock

Explanations of: evidences of elevation and depression; changes of sea level; how submergence and emergence occur; why diastrophism occurs; how folding and faulting occur; the elastic rebound theory; causes of earthquakes; origin of tsunamis; use of the seismograph; California's earthquakes; east Canadian earthquakes

Descriptions of: land forms produced by faulting; destruction by earthquakes; the earthquake belts; North American earthquakes

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. What is diastrophism? Why are we returning to study it now?

2. (*a*) How do marine fossils, raised beaches, and sea caves show that the earth's crust has been elevated? (*b*) What is the submarine canyon of the Hudson? How does it show that the earth's crust has been depressed?

3. (*a*) What evidences are there that slow rise and fall of the land have occurred in "recent" times? (*b*) Give an instance of recent sudden rise of land.

4. What physiographic events cause sea level to change? Explain.

5. (*a*) What is meant by the submergence of land? (*b*) What is meant by the emergence of land?

6. Give two explanations of why diastrophism occurs.

7. (*a*) How does slow diastrophism affect horizontal rock structure? (*b*) With the aid of diagrams, explain what anticlines and synclines are. (*c*) What is a fault plane? faulting? (*d*) How does faulting affect rock structure?

8. (*a*) How is faulting explained by the elastic rebound theory? (*b*) How are earthquake shocks related to faulting and the fault line? (*c*) Why do earthquakes occur repeatedly in the same places?

9. How do volcanoes cause earthquakes? How do such earthquakes compare with those caused by faulting?

10. Describe some of the land forms produced by faulting.

11. (*a*) What evidence is there of faulting in the ocean? (*b*) Define and describe a tsunami.

12. Describe the variety of ways by which an earthquake may cause destruction. Give examples.

13. Discuss the effect of foundation and construction on a building's resistance to earthquake shock.

14. (*a*) Define seismograph, earthquake focus, and epicenter. (*b*) What three features of an earthquake can be determined from the record of a single seismograph? Explain. (*c*) How can the epicenter of an earthquake be found? (*d*) How are "earthquakes" used in oil prospecting?

15. (*a*) Describe the two principal earthquake belts. (*b*) Besides earthquakes, what else do these belts locate?

16. (*a*) What is the principal earthquake region of the United States? (*b*) Where else in the United States have severe earthquakes occurred?

GENERAL QUESTIONS

1. Slight earthquakes occur in the vicinity of Niagara Falls every few years. What is the probable cause?

2. Why are accurate maps of the sea floor important for cable companies?

3. Compare the location of zones of greatest damage in earthquakes caused by faulting and by volcanic action.

4. Why should earthquake damage be greater in buildings with foundations in mantle rock rather than bedrock?

STUDENT ACTIVITIES

1. Collecting pictures illustrating earthquakes
2. Making models to illustrate folding and faulting
3. Making maps to show earthquake regions of the United States

SUPPLEMENTARY TOPICS

1. Other Evidences of Elevation and Depression
2. Description of the Submarine Canyon of the Hudson
3. Great Earthquakes of History
4. The Tsunami
5. The Seismograph
6. Earthquake Forecasting
7. Earthquakes in eastern Canada
8. The Dogger Bank in the North Sea

TOPOGRAPHIC SHEET

Fault line scarp: McLean Bay, N.W.T. 75L/8

SUGGESTIONS FOR FURTHER READING

The Sea Around Us, by R. Carson. Oxford University Press, New York, 1951.

Our Mobile Earth, by R. A. Daly. Scribner, New York, 1926.

Great Earthquakes, by Davison. Murby, London, 1936.

Earthquakes, by Dutton. Putnam, New York, 1904.

Earthquakes, by W. H. Hobbs. Appleton-Century, New York, 1907.

Causes of Catastrophe, by D. Leet. Whittlesey, New York, 1948.

(*Also see list of suggestions for further reading at the end of Chapter* 5.)

Chapter 11

VULCANISM AND VOLCANOES

1. What vulcanism does. Temperatures rise higher and higher with increasing depth in the earth, and it was once believed that all the rock underneath the earth's outer crust was in a molten state. Today, however, most scientists agree that, in spite of the high temperatures, the earth's interior rock is probably unable to melt because of the tremendous pressure of the crust. Consequently the interior rock is solid *except in regions where the pressure is relieved by breaks or faults in the crust.* In these regions the hot liquid magmas may force their way out of the crust in spectacular volcanic eruptions, or, failing to reach the surface, they may cause faulting or slow rising of the overlying rock layers over vast areas of the earth. These movements of liquid rock, both inside and outside of the earth's crust, are classed as *vulcanism* (*vul* kun iz'm).

Vulcanism ranks with diastrophism as one of the great forces that builds up the surface of the earth. Volcanic eruptions, representing the outside or *extrusive activities* of vulcanism, create great volcanic peaks and volcanic plateaus. Spectacular as they are, however, volcanic eruptions represent but a small fraction of the total work of vulcanism, most of which is carried on mysteriously beneath the surface. These *intrusive activities* of vulcanism are revealed when the erosion of surface rock layers exposes deep-formed *intrusive igneous rock.* Many of the great mountain ranges of the world are found to have cores of igneous granite, silent evidence of the major part played by vulcanism in the elevation of the crust of the earth.

EXTRUSIVE ACTIVITIES

2. How lava comes out. Wherever hot liquid lava reaches the earth's surface, volcanic eruption is said to take place. The lava may emerge from the crust in many different ways. In Iceland, lava may flow out along the entire length of narrow fissures many miles long. In the Hawaiian Islands, lava may pour out of circular openings or craters at the tops of mountains, or through small fissures in mountainsides. Again in Iceland, the lava may flow out of a whole series of craters located along a single fissure.

When liquid lava pours out of the earth's crust, either through fissures or craters, it flows downhill until it hardens into *lava rock,* such as obsidian, rhyolite, pumice, basalt, or scoria. But in many eruptions the lava is blown out of the earth in violent explosions that hurl the hot liquid miles high into the air. In

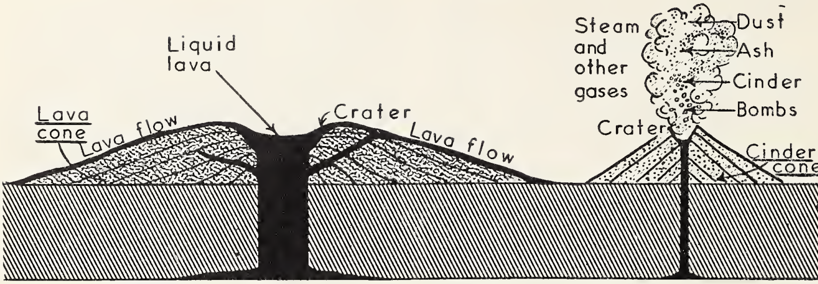


Fig. 11–1. The forms in which lava may be erupted from volcanoes. The type of eruption at the left is characteristic of Hawaiian volcanoes. The type at the right is characteristic of many Mediterranean volcanoes.

such cases the lava spray cools and hardens into solid fragments while still in the air. The tiniest droplets of this spray may form a *volcanic dust* fine enough to be carried hundreds or even thousands of miles in the upper atmosphere before descending to the surface of the earth.

Larger droplets of lava harden into fragments equivalent in size to silts, sands, and pebbles. These fragments are known as *volcanic cinders* (coarse) and *volcanic ash* (fine), because they are about the same size and consistency as cinders and ashes. Volcanic cinders and ash, however, do *not* represent burnt-out material. Volcanic cinders and volcanic ash are heavy enough to fall comparatively close to the openings from which they are erupted. Occasional large masses of lava solidify in the air as *volcanic bombs,* so called because of their size and shape, *not* because of any explosive quality.

Fig. 11–2. An eruption of steam and volcanic ash from the crater of Vesuvius. Notice the small cone which has been built up inside the crater.

Italian State Tourist Office

Explosive eruptions often shatter great masses of the solid rock through which the eruption occurs. This shattered rock is mixed with the erupting lava, adding to the total quantity of dust, cinder, and bombs produced by the eruption.

3. Gases from volcanoes. Pumice and scoria form as a result of the hardening of lava while gas bubbles are still present. Lavas contain many different gases, including steam (water vapor), carbon dioxide, hydrogen sulfide, and hydrogen chloride, among many others. Some of these gases are poisonous, and all of them are intensely hot as they escape from the lavas during eruption. Great quantities of condensing steam, mixing with fine volcanic dust and ash in an explosive eruption, often form a gigantic dark cloud reaching miles into the air over an erupting volcano.

4. Building a cone. Except in fissure eruptions, volcanic eruptions almost always cause the formation of cone-shaped piles of lava or lava fragments, built up around the opening in the earth from which the eruption occurred. The cone is formed because the lava material spreads fairly evenly in all directions from the central opening and because more material piles up nearer the opening than farther away. As volcanic eruption continues, cones may grow larger and larger in size, until they become hills or mountains. The world's greatest cone, Mauna Loa in Hawaii, has a circumference of about 400 miles at its base on the floor of the Pacific Ocean, above which it rises to a height of nearly 6 miles. This great pile represents the accumulations of more than a million years of eruptions.

The term *volcano* refers to the actual opening in the crust through which eruption takes place. The *volcanic cone*, sometimes also spoken of as the volcano, is the pile of volcanic material. Most cones have a cup-like depression at their tops, through which eruptions usually occur. These are called *craters* (see Figure 11–1).

5. Birth of a volcano. The development of a new volcano in recent times is illustrated by the Parícutin volcano, which is 200 miles from Mexico City. Early in February, 1943, a series of slight earthquake shocks disturbed the residents in and near the village of Parícutin, a farming community. For weeks the shocks continued, until on February 20 a number of cracks appeared in a perfectly level corn field, hardly more than a mile from the village. Fiercely hot gases escaped into the air, and were soon followed by blasts which shattered the earth and opened outlets through which lava and cinders were ejected.

Courtesy Soil Conservation Service

Fig. 11–3. The volcano Parícutin, 10 months after its birth on February 20, 1943. The lava in the foreground is still hot, and ash is erupting from the crater of the 1500-foot high cinder cone.

Eruptions and earthquakes continued to rock the area, and in May the volcano became so violent that it was necessary to evacuate the residents for many miles around, lava flows even reaching into the village. By September, 1943, Parícutin's volcano had built up a cone-shaped mountain 1500 feet high and about a mile in diameter! In 1944 a great outpouring of lava flowed more than 5 miles from the volcano to bury all but the church steeple of the village of San Juan de Parangaricutiro. Parícutin became less active after this, but 8 years later, in 1952, it was still pouring out lava at the rate of 200,000 tons a day. Even if Parícutin becomes extinct, it will be many years before erosion destroys its work.

6. Types of volcanoes. Volcanoes are classified into three principal types according to the kind of eruption. *Explosive volcanoes* erupt with terrific violence, blowing great quantities of lava and shattered rock high into the air. *Quiet* or *oozing volcanoes* erupt comparatively quietly, with lava overflowing from their craters or flowing out of fissures on the sides of the cones. *Intermediate volcanoes* are those whose eruptions are intermediate in type between the other two—sometimes explosive, sometimes quiet, or a combination of both.

7. Volcanoes that explode. Violent volcanic eruptions are believed to occur in volcanoes whose craters are plugged up by the solidification of old lava, or in which the magma is so thick that gases cannot escape. Gases accumulate in these volcanoes until the terrific pressure blows out the rock plug with a mighty explosion. Shattered rock, liquid lava spray, great volumes of steam, and many other gases combine to form a fiercely hot and destructive cloud above the erupting cone. There is practically no flow of liquid lava in an explosive eruption. The cone is built up almost entirely of the solid fragments that fall to the earth on all sides of the volcanic opening, piling up highest near the opening. Composed largely of volcanic cinders or ash, the cones of explosive volcanoes are called cinder cones (Figures 11–1 and 11–3). Like piles of ordinary furnace ashes, cinder cones have *steep slopes* (up to about 35 degrees) and rather *narrow bases.* The loose materials of these cones are very rapidly removed by erosion, and cinder cones formed above the ocean floor are worn away almost as fast as they are formed.

Explosive volcanoes have been known to erupt so violently as to blast away a large part of their cones. This happened to the volcano Krakatoa in the East Indies in 1883, and to the volcano Katmai in Alaska in 1912. Another famous example of an explosive volcano is Pelée on the island of Martinique in the West Indies.

8. Quiet or oozing volcanoes. In contrast to the eruptions of explosive volcanoes, very little solid material is ejected from a quiet volcano. The magma of the quiet volcano is thin enough to allow the steady escape of dissolved gases, and its broad crater is but thinly covered by solidified lava. Even between eruptions, "lakes" and "fountains" of fiery liquid lava may be seen in some craters. Eruptions occur when internal pressure causes lava to rise in the crater and overflow or to break through fissures in the sides of the cone. There is little violence in these eruptions, but the blazing-hot lava destroys everything in its path. Slowly solidifying as it flows, the lava spreads far and wide to form a *broad, gently sloping lava cone,* which

United States Army Air Force

Fig. 11–4. Aerial view of the summit of Mauna Loa, great Hawaiian volcano. The giant crater at the mountain top is 3 miles in diameter. Note particularly the gentle slopes of this broad lava cone, only a fraction of which appears in this photo.

is much more resistant to erosion than a cinder cone. Its slopes are usually less than 10 degrees.

Typical quiet or oozing volcanoes occur in the Hawaiian Islands and in Iceland. Mauna Loa and Kilauea, both on the island of Hawaii, are perhaps the most famous of all volcanoes of this type. Mauna Loa's slopes of approximately 6 degrees are so gentle that it is difficult to believe that they are the flanks of a giant volcanic cone rising over 30,000 feet from the ocean floor and almost 14,000 feet above sea level. Its steep-walled, oval-shaped crater is about 3 miles in diameter. (Incidentally, the city of Honolulu is not on the island of Hawaii, but on the smaller island of Oahu, which has no active volcanoes.)

While most lava cones are gentle in slope, there are some exceptions. Very thick lavas that move slowly and cool quickly may form cones almost as steep as cinder cones. An example is Mount Chimborazo, a great volcano of the Andes Mountains, with a steep lava cone.

9. Intermediate volcanoes. Most volcanoes of the world are of the intermediate type. This usually means that their eruptions are neither entirely explosive nor entirely quiet, but combine features of both. Such eruptions often begin with explosions of cinder from the craters, and are followed by flows of lava through fissures in the sides of the cones. The cones of these volcanoes are steeper than lava cones but gentler than cinder cones. Their average slope is between 20 and 30 degrees. Being made of layers of both lava and cinder, they are called *composite cones.* In general,

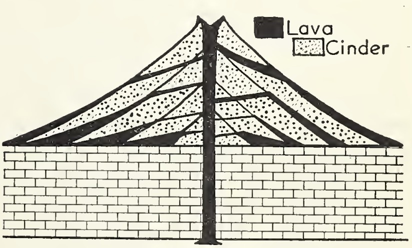


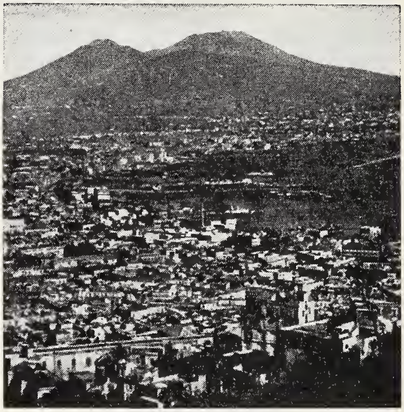
Fig. 11–5. Sketch of the composite cone of an intermediate volcano such as Vesuvius.

the more lava in the cone, the gentler its slopes and the broader its base. Examples of intermediate volcanoes are Mount Vesuvius in Italy, Mount Fujiyama in Japan, Mount Popocatepetl in Mexico, Mount Rainier in the state of Washington, and Mount Etna in Sicily.

10. Eruptions from fissures. As discussed in Topic 2, quiet eruptions of lava may occur in long earth fissures as well as from the circular openings of volcanoes. Instead of forming cone-shaped mountains, the spreading lava flows of these fissures form comparatively level and very extensive *lava plains* or *lava plateaus*. The best examples of fissure eruption in modern times are those of Iceland. Numerous fissure eruptions of past ages are believed to have built up the great Columbia lava plateau of northwestern United States and the great Deccan plateau of India, as well as such smaller lava plateaus as those in Yellowstone National Park.

11. Is the volcano alive? To indicate the "liveness" of a volcano, the terms *active, dormant,* and *extinct* are used. An *active* volcano is one which erupts occasionally in our own times. A *dormant* (sleeping) volcano is one which has erupted in modern times, but not very recently. An *extinct* volcano is one that has not erupted within historic time. These terms are more or less relative. Now and then an "extinct" volcano such as Mount Vesuvius in Italy or Lassen Peak in the United States suddenly becomes active, and there is no real security for the people who live in the immediate vicinity of a dormant volcano.

People do not ordinarily choose to settle near active volcanoes, but in some cases the attraction of fertile soil recently weathered from volcanic rocks, together with other natural advantages of climate and location, appears to be too great to resist. In many cases, people are misled by a kind of optimism. Although recognizing the danger, they say "It can't happen to me." Outstanding examples of densely settled volcanic regions are those near Vesuvius, Etna, and Mount Pelée. All these regions have suffered disastrous eruptions within historic times, and after each eruption those still living return bravely and optimistically to rebuild their homes.



Courtesy Italian State Tourist Office

Fig. 11–6. The great city of Naples lies in the shadow of the composite cone of Mount Vesuvius.

12. Famous eruptions. Space does not permit full descriptions of some of the great eruptions of history, but a few interesting highlights can be presented.

Mount Pelée. Three miles from the crater of "dormant" Mount Pelée on the West Indian island of Martinique stood the capital city of St. Pierre. The inhabitants of that city expected no harm from a volcano that had been inactive since 1851. When the volcano showed signs of activity in April of 1902, few of the nearly 30,000 inhabitants paid any

attention until it was too late. On May 8 a terrific explosion tore open the crater, and a great cloud of hot poisonous gases and volcanic fragments swept down upon the city to scorch and smother to death the entire population. The only survivor was a prisoner in the city jail who apparently owed his life to the poor ventilation of the deep dungeon in which he was kept.

Krakatoa. Krakatoa is a volcanic island in the East Indies between Java and Sumatra. On August 27, 1883, an explosive eruption took place which is usually described as "the most violent eruption of historic times." More than half of the island—over a cubic mile of rock—was destroyed and blown away in the explosion. The cloud over the volcano reached 17 miles into the air. The air wave broke windows 100 miles away, and the sound was heard 2000 miles off in Australia. Great sea waves wreaked destruction on nearby coasts, where 36,000 people were drowned, and the waves even reached the shores of South Africa, over 5000 miles away. The fine volcanic dust from the eruption was carried completely around the world by the winds of the stratosphere. Taking months to drift down to the earth's surface, the dust produced strangely beautiful skies throughout a large part of the world for a long time after the eruption.

Mauna Loa. "Quiet" Mauna Loa has been consistently active in recent times, with eruptions occurring irregularly at intervals of about 8 years. Between eruptions, the great oval crater, 3 miles long and 2 miles wide, is crusted over by basalt rock underneath which lies hot molten lava. The coming of an eruption is usually foretold by the rise of lava in the crater. Breaking the crust at various points, the white-hot lava spurts up in "fountains" hundreds of feet high. Before the lava can rise high enough to overflow the crater, it usually breaks through fissures on the volcano's sides. As these fissures split open, earthquakes may occur in the vicinity. The outflowing lava forms streams up to a mile in width and 40 miles in length, sometimes running into the ocean. In recent years, when lava flows from Mauna Loa threatened to destroy the village of Hilo on the northeast coast of Hawaii, United States Army planes dropped bombs on the flows in an attempt to make them turn away from Hilo. The flows stopped before reaching Hilo, however.

13. Distribution of volcanoes. Most of the volcanoes of the world lie in two great belts which are almost identical with the earthquake belts described in the last chapter. Outstanding in the Pacific belt are the volcanoes of the Andes Mountains of South America, Alaska, the Aleutian Islands, Japan, the Philippines, and New Zealand. In the Mediterranean belt are the volcanoes of the Mediterranean region itself, the Azores, the West Indies, the Hawaiian Islands, and Asia Minor. Included in both belts where they cross are the East Indies and Central America. The volcanoes of Iceland and the Antarctic are in neither of the two great belts.

Both volcanoes and earthquakes occur along great fault lines in the earth's crust, in regions where the forces of the earth's interior are most active today in elevating the earth's surface by vulcanism and diastrophism.

14. Volcanoes of North America. The only active volcano in the United States is Lassen Peak in Lassen Volcanic National Park, California. This volcano was "extinct" until 1914, when it suddenly became active. Alaska has two great active volcanoes, Katmai and Aniakchak. In 1912 Katmai had an ex-

Fig. 11–7. Black dots show the location of the principal active volcanoes of the world.

plosive eruption rivaling that of Krakatoa's in violence. Mexico has, besides the new-born Parícutin, three great volcanoes which rank among the highest mountains in North America. The best known of these is Popocatepetl; the other two are Orizaba and Ixtaccihuatl. There are no active volcanoes in Canada.

Cones of recently extinct volcanoes include Edziza Peak (9140 feet) in northwest British Columbia, Mount Rainier (14,408 feet) in Washington, Mount Hood (11,225 feet) in Oregon, and Mount Shasta (14,162 feet) in California.

15. Life history of a volcanic cone. The life history of a volcanic cone portrays in miniature the struggle that goes on all over the earth between the constructional forces of the earth's interior and the destructional forces of weathering and erosion. No sooner does a volcanic cone come into existence than it is attacked by weathering and erosion. Weathering and erosion work steadily and ceaselessly, while the building of the cone can occur only during eruptions. In *youth,* the *active* volcano builds its cone faster than it is eroded, and the cone grows tall and symmetrical (evenly shaped). When the volcano becomes *extinct,* weathering and erosion soon wear gullies and valleys into its once-smooth slopes, and the volcanic cone is said *to be in maturity.* As erosion continues, it wears away the lava and ash layers more rapidly than the hard plug of intrusive rock below the crater. In time, this plug may be left standing high above the remnants of the slopes of the volcano in *old age.* The plug is also known as a *volcanic neck.*

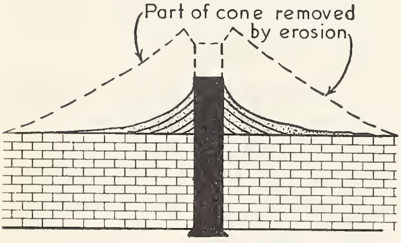


Fig. 11–8. Diagram showing the origin of a volcanic neck.

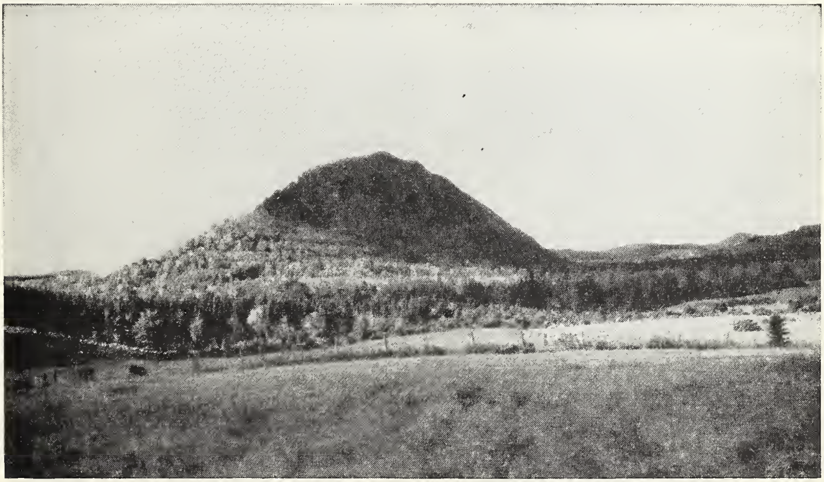
All active volcanoes are young. So are recently extinct volcanoes which are as yet hardly affected by erosion. Mount Shasta and Mount Hood are good ex-

amples of mature volcanoes. The necks of old volcanoes may be seen in many parts of western United States as spectacular, steep-walled masses of dark rock projecting above otherwise level or rolling landscapes. The Monteregian Hills in the St. Lawrence Valley, including Mount Royal, are probably volcanic necks. The 600-foot-high Devil's Tower in Wyoming is a famous volcanic neck in the United States. Volcanic necks form the diamond-bearing rock of the great Kimberley mines of South Africa.

16. Lakes in craters. Rain and melting snows partly fill the craters of some extinct volcanoes to form *crater lakes.* In a few cases the craters have been tremendously enlarged, either by violent explosions that blew off the top of the volcano (as at Mount Katmai in Alaska) or by sinking of the top of the volcano into the lava below its crater floor (as in the Hawaiian volcanoes). Crater

Courtesy Burlington Lines

Fig. 11–9. The 600-foot-high Devil's Tower in Wyoming is a famous volcanic neck. Its rock shows the columnar structure that developed in it during the cooling of its magma.



F. J. Alcock, Geological Survey of Canada

Fig. 11–10. Sugar Loaf Mountain, near Campbelltown, New Brunswick. An old volcanic neck.

Lake in Crater Lake National Park, Oregon, may have been formed by either of these processes. Its nearly circular crater is 6 miles in diameter, with cliff-like walls rising in places more than 2000 feet above the surface of the lake, which reaches a maximum depth of about 2000 feet. Crater Lake is the deepest lake in North America. A small cone, apparently formed after the destruction of the volcano top, rises from the crater floor as a small island in the lake. It is called Wizard Island.

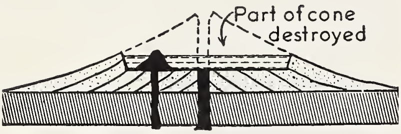


Fig. 11–11. Sketch showing how a crater lake's basin may form.

INTRUSIVE ACTIVITIES

17. Dikes. The presence of igneous intrusions in the bedrock can be discovered only after erosion removes the overlying rock masses. Intrusions of magma into vertical or fairly vertical cracks in bedrock are called *dikes* (see Figures 11–13 and 11–14). They vary in width and thickness from inches to hundreds of feet and in length up to many miles. Dikes may be either harder or softer than the rock they penetrate. If they are harder, weathering and erosion will leave them projecting above the rest of the bedrock. Hard dikes in the bed of the Yellowstone River are responsible for the formation of Yellowstone Falls, as explained in Chapter 8.

18. Sills or sheet. In stratified rocks, dikes cut more or less vertically *across* the rock layers. Occasionally, hot magma forces its way *in between* sedimentary rock layers over a large area, forming a *sill* or *sheet* of igneous rock when it hardens. Sills may be hundreds of feet in thickness, miles wide, and many miles long. When a river cuts a canyon through the rock of a region in

Fig. 11–12. Crater Lake and Wizard Island. Wizard Island is a small cone like that shown inside the crater in Fig. 11–11.

Courtesy Southern Pacific

Fig. 11–13. Diagram showing the kinds of rock masses produced by igneous intrusion.

which a sill is buried, the sill is exposed to view between the sedimentary layers into which it was intruded. The igneous rock of the sill often forms the steepest part of the valley wall. It was in this manner that the cliffs known as the Palisades of the Hudson River in New York and New Jersey were formed. The Palisades represent the face of a great sill hundreds of feet thick and 30 miles long. Talus from the Palisades collects at its base and covers the sandstone layers that lie beneath the igneous diabase rock of the sill (Figure 11–15).

Fig. 11–14. An igneous dike cutting through limestone, Mount Royal, Montreal.

I. A. McKay

19. Laccoliths. Thick magma rising to the surface may meet layers of rock which it can neither penetrate as in a volcano nor pass between as in a sill. In such cases the magma often forces the overlying layers upward in a great oval or circular dome, below which the magma hardens into crystalline igneous rock. The mass of igneous rock, shaped like a great mushroom with a vertical thickness up to a mile and a diameter up to many miles, is known as a *laccolith* (*lak* o lith). *Lacco* means lake; *lith,* stone. The dome formed on the earth's surface by the lifting of the overlying rock, when large enough, is known as a domed mountain. Many of the smaller mountain regions of the United States, such as the Henry Mountains of Utah and the Black Hills of South Dakota (see Figure 11–16), are groups of domed mountains in which the igneous laccoliths are partly exposed by erosion of the overlying sedimentary strata.

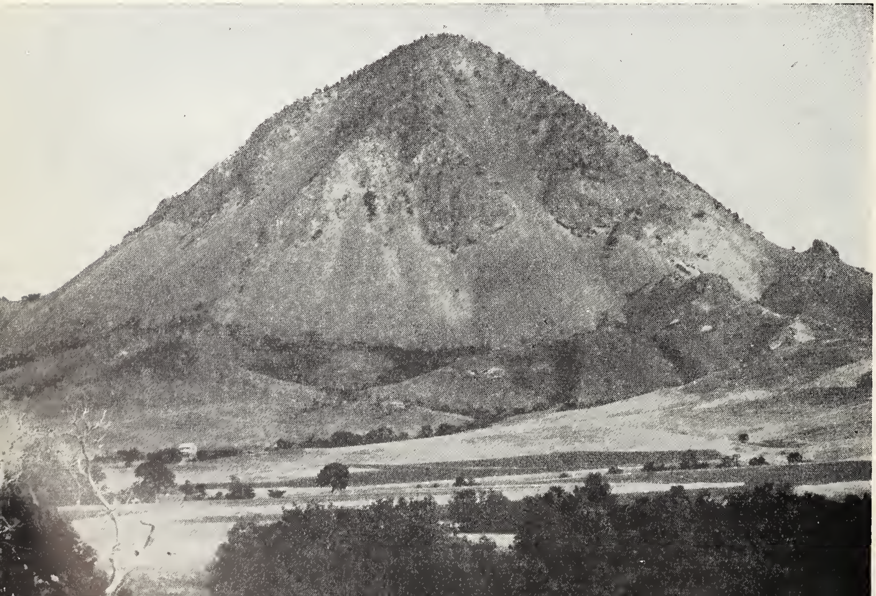
20. Stocks and batholiths. Erosion often exposes very large masses of igneous rock which are circular or oval in shape and many miles in diameter. Unlike laccoliths, these masses seem to extend to indefinite distances inside

Courtesy New York Central System

Fig. 11–15. The Palisades of the Hudson River is a sill that has been exposed to view by weathering and erosion. Note the columnar structure of the rock and the talus at the cliff base.

Fig. 11–16. A laccolith—Bear Butte, South Dakota. The sedimentary rocks that once covered this igneous intrusion have been eroded away everywhere except at the mountain base.

U.S. Geological Survey



the earth's crust, broadening as they go deeper. These *stocks* or *bosses* were apparently formed as great intrusions of magma. Similar but much larger masses of igneous rock, less regular in shape and covering areas of hundreds or even thousands of square miles, are called *batholiths* (*batho*, depth; *lith*, stone). Exposed by erosion, batholiths are seen as the cores of parts of great mountain regions such as the Coast Mountains in British Columbia.

HAVE YOU LEARNED THESE?

Meanings of: vulcanism; active, dormant, and extinct; dike, sill, and laccolith

Diagrams and descriptions of: a volcanic cone, dikes, sills, laccoliths, stocks, and batholiths

Explanations of: the melting of rock below the earth's crust; types of volcanoes; fissure eruptions; the effects of intrusive and extrusive vulcanism; the relation between vulcanism and mountains

Origin of: lava cones; cinder cones; composite cones; volcanic dust, ash, cinder, and bombs; Crater Lake; Palisades of the Hudson River

Examples of: explosive, quiet, and intermediate volcanoes; fissure eruptions; volcanoes in each of the two great belts; volcanoes of the United States; sills; laccoliths

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) Why is the earth's interior rock believed to be molten only near breaks in the crust? (*b*) What does the liquid magma do in these places? (*c*) Define vulcanism, and explain why it is regarded as a great upbuilding force. (*d*) Compare the results of extrusive and intrusive vulcanism.

2. Describe the different ways in which lava may come out of the earth's crust, and the different forms it takes.

3. What gases may be erupted from a volcano?

4. Sketch and label the parts of a volcanic cone, and explain how the cone gets its shape.

5. Give a brief history of the Parícutin volcano.

6. Explain the classification of volcanoes as explosive, quiet, and intermediate.

7. (*a*) Describe the eruption of an explosive volcano. (*b*) Describe the cone made by an explosive volcano. Name examples.

8. (*a*) Describe the eruption of a quiet volcano. (*b*) Describe the cone made by a quiet volcano. (*c*) Where do quiet volcanoes occur? Give examples.

9. (*a*) Describe the eruption of an intermediate volcano. (*b*) Describe a composite cone. Give examples.

10. Describe the results of past and present fissure eruptions.

11. (*a*) What is meant by the terms *active*, *dormant*, and *extinct* volcanoes? Why are they "inexact"? (*b*) Why do people settle near active volcanoes?

12. Give some of the highlights of the eruptions of Mount Pelée, Krakatoa, and Mauna Loa.

13. (*a*) Describe the two great volcanic belts. (*b*) Why do volcanoes and earthquakes occur in the same regions?

14. (*a*) Name some of the active volcanoes of North America. (*b*) Name some of the extinct volcanoes of North America.

15. (*a*) Give a brief description of the life history of a volcanic cone. (*b*) Give examples of young, mature, and old volcanic cones.

16. Describe Crater Lake, and explain its origin.

17. What are dikes? How do they become exposed at the earth's surface? How are dikes related to Yellowstone Falls?

18. (*a*) Compare sills with dikes as to origin, position, and size. (*b*) How does a sill become exposed to view? (*c*) Describe the Palisades of the Hudson River as to origin and size.

19. (*a*) How is a laccolith formed? (*b*) What is a domed mountain? (c) Where can laccoliths be seen?

20. (*a*) What is a stock? a batholith? (*b*) How are batholiths related to mountains?

GENERAL QUESTIONS

1. In the Hawaiian volcanoes, lava breaks through fissures far more often than it overflows from the craters. How does this affect the shape of the volcanoes? Explain.

2. How is it possible for glaciers to exist on the slopes of an active volcano?

3. (*a*) Why are batholiths likely to contain different textures of rock than sills or laccoliths? (*b*) What kinds of igneous rock (granite, basalt, obsidian, gabbro, etc.) are batholiths likely to contain? Why?

4. How is Wizard Island in Crater Lake known to have formed after the original crater caved in?

5. How can a geologist know that a laccolith is not a stock?

6. What evidence tells us that dikes and sills were not formed at the same time as the rocks in which they occur?

7. What conditions would produce the most symmetrically shaped volcanic cone?

8. Make a contour map of a volcanic cone with two rivers running down opposite sides.

9. In what ways would the eruption of a volcano under water differ from an eruption on land?

10. Why may the sky glow red above an active volcano at night, even when it is not erupting?

STUDENT ACTIVITIES

1. Making clay, plaster of Paris, or papier maché models of: (*a*) volcanic cones of different types, (*b*) a volcanic neck, (*c*) igneous intrusions, (*d*) the Palisades of the Hudson
2. Making drawings or paintings of the features listed in number 1 above
3. Collecting pictures of volcanoes and other features of vulcanism
4. Collecting samples of volcanic rocks
5. Making field trips to see local features produced by vulcanism
6. Visiting museum displays related to vulcanism
7. Studying contour maps of volcanoes

SUPPLEMENTARY TOPICS

1. Famous Volcanic Eruptions
2. Economic Products of Volcanoes
3. Aa and Pahoehoe Lava in Hawaii
4. The Craters of Volcanoes
5. The Valley of Ten Thousand Smokes in Alaska
6. Volcanic Necks
7. Crater Lake, Oregon
8. The Palisades of New Jersey
9. The Devil's Tower, Wyoming
10. Mount Royal, Montreal

TOPOGRAPHIC SHEETS

1. *Young volcano:* Lassen Volcanic National Park, California.
2. *Mature volcano:* Mt. Shasta, California
3. *Volcanic necks:* Shiprock, New Mexico

SUGGESTIONS FOR FURTHER READING

Our Mobile Earth, by R. A. Daly. Scribner's, New York, 1926.

Volcanoes of North America, by I. C. Russell. Macmillan, New York, 1897.

Living Africa, by B. Willis. Whittlesey, New York, 1930.

Volcanology, by Day. National Research Council, Washington, D.C.

(See list of suggestions for further reading at the end of Chapter 5.)

Chapter 12

PLAINS, PLATEAUS, AND MOUNTAINS

1. Physiographic regions. A tourist making a trip across Canada from Halifax to Vancouver, might pass in order through the following regions (see Figure 16–1): The Appalachian Uplands, the St. Lawrence Lowlands, the Canadian Shield, the Interior Lowlands (of Manitoba) the Great Plains (of Saskatchewan and Alberta), and the Western Cordillera (subdivided into the Rocky Mountains, the Interior Plateau and the Coast Ranges). Each one of these *physiographic regions* represents a large area of the country in which the *rock structure* and *topography* are fairly uniform throughout. Adjoining regions differ from each other in the kinds of bedrock they have, in the arrangement of their bedrock, and in their topography. To the tourist, these differences are likely to appear only as changes in the scenery, but to the physiographer the differences go deeper than the surface.

Looking at the list of physiographic regions in the preceding paragraph, we see that, excluding the complex Appalachian and Shield regions, each one is a plain, plateau, or a mountain. To the physiographer these plains, plateaus and mountains are the *major land forms* of the continents, and it is upon them

U.S. Geological Survey

Fig. 12–1. Relief Model of North America.

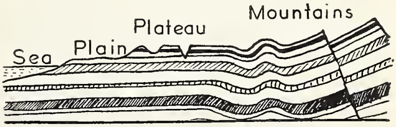


Fig. 12–2. Diagram showing the horizontal rock structure of plains and plateaus, as contrasted with the nonhorizontal or "disturbed" structure of mountains.

that the minor land forms studied in preceding chapters have been formed by weathering and erosion.

2. Plain, plateau, or mountain? How does the physiographer decide whether to call a region a plain, a plateau, or a mountain? Two different schemes are used. The older scheme classifies regions according to their surfaces. Regions with high, rugged (rough) surfaces are called mountains; regions with high, comparatively flat surfaces are called plateaus; regions with low flat surfaces are called plains.

In the newer scheme, which we shall use, land forms are classified according to their *rock structure*. Regions with horizontal or nearly horizontal rock structure (composed of horizontal or nearly horizontal stratified rocks) are either plains or plateaus, while regions with "disturbed" or nonhorizontal rock structure are mountains. (Mountains may have tilted, folded, domed, or volcanic cone structure. See Figure 12–2.)

3. Plain or plateau? Both plains and plateaus have horizontal rock structures, but they are distinguished from each other by their *relief*. Relief may be explained as the roughness of a surface, or the difference in height between the highest and lowest points of a region. For example, if the highest peak in the Shickshock Mountains is 4160 feet above sea level, and the bottom of the lowest valley in the district is 1000 feet above sea level, the relief is 3160 feet. Relief maps (like Figure 12–1) attempt to show the roughness of the surface portrayed by the map.

Let us see how plains and plateaus differ. *A plain is a region of horizontal rock structure and low relief. A plateau is a region of horizontal rock structure and high relief.* No exact amount of relief is stated, but the relief of a plain is usually not more than a few hundred feet, while that of a plateau is usually more than a thousand feet.

In this classification, we pay *no* attention to the surface of a region in deciding whether to call it plain, plateau, or mountain. "Once a mountain, always a mountain," regardless of how smooth its surface has become through erosion. Similarly, "once a plateau, always a plateau," regardless of how rugged its surface may have become (see Fig. 12–3). But we do recognize the fact that during its life history, the surface of a plain, plateau, or mountain may

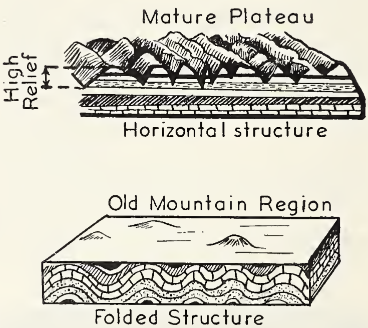


Fig. 12–3. In maturity, a plateau has a rugged surface. In old age, a mountain region has a fairly level surface.

change considerably. Because of this, we may speak of a young mountain, a mature plateau, and so on. The advantage of this newer classification is that in a few words it tells us about the rock structure, the relief, and the life history of a region rather than merely how rough or smooth its surface is.

4. How plains and plateaus originate. Since plains and plateaus are regions of horizontal rock structure, they originate by any process that deposits rock materials in horizontal layers. Rivers may deposit sediments on continental shelves, on lake floors, at

the base of mountains, or on their own flood plains. Glacial streams may deposit sediments beyond their terminal moraines. Volcanic eruptions through fissures may form horizontal layers of lava.

In some cases, the regions covered by these horizontal layers of alluvial, glacial, or volcanic materials are already parts of the dry continental areas; in other cases, they are under water and must "emerge" before they become plains or plateaus. Those regions that are high above sea level are likely to become deeply eroded and therefore have high relief. These will be known as plateaus. Regions that are not high above sea level will not be eroded deeply. They will have low relief and will be known as plains.

CLASSES OF PLAINS

Plains are usually divided into classes according to the *origin* of their sediments or rock materials.

5. Plains from the ocean. *Marine* (ocean) *plains* are plains formed by the emergence of shallow parts of ocean floors. (As explained in an earlier chapter, emergence may occur through either the rise of the ocean floor, the lowering of the ocean water, or a combination of both.) The largest plains in the world originated in this way. Marine plains may be either *coastal* or *interior* plains, depending on their locations. The Atlantic Coastal Plain, running along the Atlantic Coast from New Jersey to Florida, is a coastal plain. So is the Gulf Coastal Plain along the Gulf of Mexico (see Figure 12–1). Both of these were formed by the emergence of continental shelves. But the Great Plains region of the United States and Canada, though also a marine plain, is an interior plain, formed by the emergence of the floor of a shallow inland sea that stretched from Hudson Bay to the Gulf of Mexico millions of years ago.

Marine plains in Europe include the coastal plains of northern France, of southeastern England, and of western Scandinavia, as well as the great interior plains of central Europe and the Russian Ukraine (see Figure 12–4).

6. Plains from lakes. *Lake plains* are plains formed by the emergence (of all or part) of a lake floor. This may happen when the waters of a lake run out or evaporate, or when a lake floor rises. The greatest lake plain in North America covers an area of over 110,000 square miles (more than all the present Great Lakes) in Manitoba, North Dakota, and Minnesota. This region was once the floor of a great Ice Age lake called Lake Agassiz (*ag* a see). The natural drainage of this area is northwards toward Hudson Bay. During the Ice Age

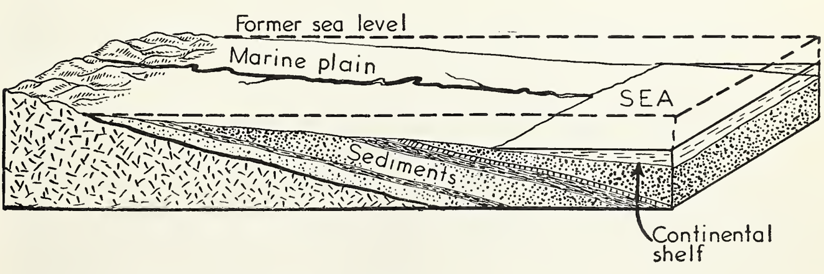


Fig. 12–4. The origin of a coastal marine plain.

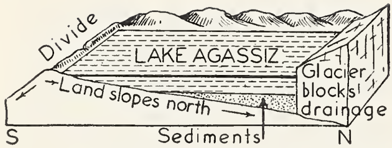


Fig. 12–5. How the Lake Agassiz plain originated.

the glacier itself blocked the drainage (see Figure 12–5), damming up the water from the melting glacial ice into a tremendous lake larger than all the Great Lakes combined. When the Ice Age ended, the lake drained away and disappeared, leaving its level floor and fine sediments as a great lake plain. Here and there a depression in the floor of Lake Agassiz retained its water and formed a small lake. The largest of these remnant lakes are lakes Winnipeg, Winnipegosis and Manitoba. Today the new Red River flows northward through the very flat lake plain. The plain is often loosely spoken of as the "valley of the Red River," but its origin as a *lake* floor should not be forgotten.

Great Salt Lake in Utah is another remnant of a once greater lake, and the Great Salt Lake Desert is a lake plain. A lake plain, narrow on the north side and broader on the south, surrounds Lake Ontario. It represents the part of the floor of Lake Ontario that was uncovered by shrinkage of the lake at the close of the Ice Age.

7. Alluvial plains, glacial plains, and lava plains. *Alluvial plains* (formed by rivers) include *flood plains, delta plains,* and *piedmont alluvial* plains, all of which were described in the chapter on streams. Glacial plains include *outwash plains* like those of southern Long Island (described in the chapter on glaciers), and *till plains.* Till plains are regions in which glacial till, deposited in hilly country, has filled in hollows and cre-

Fig. 12–6. A piedmont alluvial plain.

ated a fairly level surface. Till deposits are not stratified, so these regions should not be called plains unless the old rock structures that they cover are horizontal, as in southern Ontario and parts of the Prairies (see Figure 12–7).

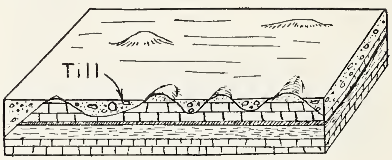


Fig. 12–7. A till plain.

Lava plains, originating in fissure eruptions or in the far-spreading lava flows of quiet volcanoes, are found in parts of Iceland and the Hawaiian Islands.

8. The life history of a plain. In its *youth,* a newly formed plain is a broad region of almost perfectly level topography. A few shallow river valleys occur at great distances from each other, and the very extensive interstream areas are so flat that drainage is poor and shallow lakes or swamps may be common. The swampy coastal plain of Florida, the muddy floor of Lake Agassiz, and the level plains of the Russian Ukraine are all examples of youth.

In *maturity* the plain is eroded by many new tributaries of the original streams. Frequent shallow valleys and narrow interstream areas create a rolling surface of low relief and good drainage. The Interior Lowlands of southern Ontario are mature plains.

In *old age* the plain is worn almost

level again, but it is covered by a very thick layer of soil and weathered rock. There are few rivers, all of them in late maturity or old age. Parts of eastern Kansas are plains in old age.

National Film Board, Canada

Fig. 12–8. Harvesting wheat on the Great Plains in Saskatchewan.

PLATEAUS

9. How plateaus are formed. The only distinction between a plain and a plateau is in their relief, and plateaus often originate as "raised plains." Thus, plateaus are usually classified to indicate *how they were raised* high enough to acquire a relief greater than that of plains.

Some plateaus are former plains that have been raised high above sea level by repeated vertical faulting through hundreds of thousands of years of recent earth history. Such plateaus may be called *fault plateaus.* The Colorado Plateau of southwestern United States is an example of a great plateau region formed largely by faulting. Its total relief is about 6000 feet. The Appalachian Plateau of eastern United States (New York, Pennsylvania, West Virginia, Kentucky, Tennessee, and Alabama) was raised slowly with little faulting, and is called a *warped plateau.* Both fault and warped plateaus are raised by the forces of diastrophism.

Vulcanism also forms plateaus. When successive horizontal lava flows build a region up to great heights, *lava plateaus* are formed—exactly like lava plains in origin, but having higher relief. The great Columbia lava plateau of Washington, Oregon, northeastern California, and southern Idaho covers an area of over 100,000 square miles (see Figure 16–1), and its lava layers are thousands of feet thick. The great Deccan lava plateau of India, roughly covering the triangle marked by the cities of Bombay, Madras, and Calcutta is even larger.

10. The life history of a plateau. The life history of a plateau is very similar to that of a plain, but high relief

Fig. 12–9. A spectacular canyon cutting the broad surface of a young plateau. Canyon DeChelly in the Navajo Reservation, northeastern Arizona.

Courtesy Santa Fe Railway

makes plateau scenery much more striking. *Young plateaus* are high and broad, and the few rivers that run through them carve out deep and often spectacular canyons or ravines. The Colorado Plateau and the Columbia Plateau are young.

As plateaus mature, increasing numbers of rivers cut many valleys and narrow their once-broad interstream areas, creating extremely rugged surfaces. The *mature plateaus,* also known as eroded or dissected plateaus, are still plateaus *because of their horizontal rock structure and high relief* (see Figure 12–3). But in their own localities they are usually known as "mountains." The Appalachian Plateau of eastern United States —high, rugged, and densely forested up to its even skyline—is a mature plateau, portions of which are known locally as the Catskill Mountains (in eastern New York), the Pocono Mountains and Allegheny Mountains (in Pennsylvania and West Virginia).

In old age most of a plateau is worn down almost to base level, and the region may be called a peneplane, which was explained in Chapter 8. Here and there a few hard-capped hills, perhaps the last remnants of the old interstream areas, remain standing high enough to maintain the high relief of a plateau. Where these hills are flat-topped and broad, they are called *mesas.* Smaller, narrow-topped hills are called *buttes* (*bewts*). Both mesas and buttes have

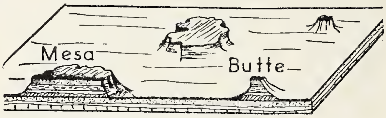
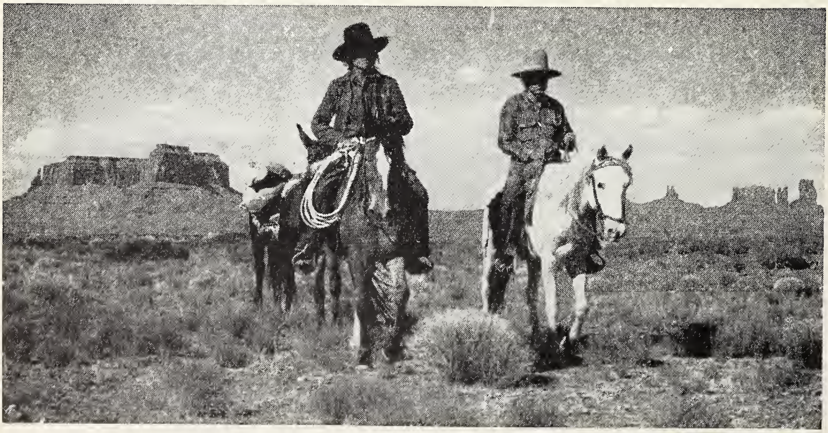


Fig. 12–10. A plateau in old age.

steep, cliff-like walls, sometimes hundreds of feet high, which isolate them from the rest of the plateau. Portions of Arizona, New Mexico, and Texas are old plateau regions. Plateaus by the definition used in this chapter are rare in Canada and are restricted to the low hills along the United States border in the Prairies, and plateaus in the Canadian Arctic.

MOUNTAINS

11. How mountains originate. Mountains are regions of *disturbed* or *nonhori-*



Courtesy Santa Fe Railway

Fig. 12–11. Buttes and mesas rising above the plateau surface.

U.S. Geological Survey

Fig. 12–12. Parallel ridges of the folded Appalachian Mountains.

zontal rock structure. Mountains may originate through either diastrophism or vulcanism. Diastrophism may "disturb" horizontal rock layers by folding them or by faulting and tilting them (see Chapter 10). Vulcanism may disturb horizontal rock layers by *doming* them, or may make nonhorizontal layers by eruptions which form the sloping beds of volcanic cones (see Chapter 11).

12. Forming mountains by folding. When diastrophism causes slow crumpling of a portion of the earth's solid crust, horizontal layers of sedimentary rock may be folded up to great heights. Pushed into numerous long parallel ridges, these disturbed rock strata form *folded mountains* whose length may approach a thousand miles. The upfolds of the rock strata are known as *anticlines;* the downfolds are known as *synclines* (see Chapter 10). (Anticlines and synclines should not be confused with hills and valleys, which are features of surface topography, not of the rock structure.)

Many of the great mountain ranges of the world, including the Rocky Mountains, the Coastal Range off the B.C. Mainland, the Alps, the Himalayas, the Alaskan Ranges, and the Andes, have been formed at least in part by the folding of rock strata. In almost every case these mountains run parallel to the margins of their continents, and are now or were once near the sea coast. According to the theory of isostasy (see Chapter 10), this is exactly where great movements of the earth's crust should take place as the sediment-laden sea floors, by their sinking, force up the adjacent areas of the continents (see Figure 12–1).

13. Mountains formed in blocks. When diastrophism raises and tilts large

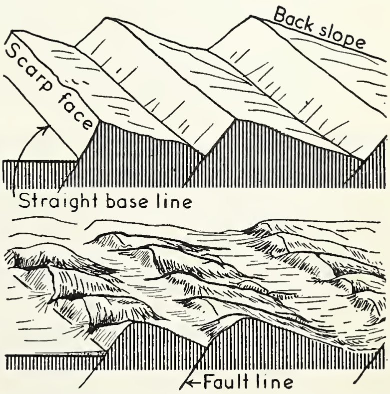


Fig. 12–13. Block mountains before erosion (above) and after erosion (below).

blocks of the earth's crust by faulting, *block mountains* (also called fault-block mountains) are formed. Particularly in youth, these mountains are characterized by long straight base lines running along their fault scarps (see Figure 12–13). The fault-scarp face of the mountain is also much steeper than the gentle back slope.

Block mountains are usually rectangular in shape and several times as long as they are wide. They vary greatly in size. Some blocks may be but a few miles in length and only a thousand feet high. Others may be hundreds of miles in length and many thousands of feet high. Small block mountains abound in the Great Basin areas of Nevada, Utah, and Oregon. The Wasatch Range in Utah is over 100 miles long and almost a mile high. The Sierra Nevada Mountains, largest of all block mountains in the United States, are over 400 miles long. Facing eastward, the steep fault scarp of the Sierra Nevadas forms one side of the Great Basin.

14. Mountains like domes. When the intrusion of a laccolith arches up the overlying rock layers (as explained in Chapter 11), domed mountains are formed. Larger domes are formed by the intrusion of batholiths. Domed mountains should not be confused with folded mountains. Domed mountains have igneous rock cores, are usually oval or circular in shape, and their diameters rarely exceed 150 miles. Folded mountains have no igneous cores, and they consist of numerous long parallel ridges whose length may reach a thousand miles. The Black Hills of South Dakota and the Adirondack Mountains are examples of domed mountains. Small

Fig. 12–14. Part of the Keewatin peneplane, west of Hudson Bay near Chesterfield Inlet, Northwest Territories.

National Film Board, Canada

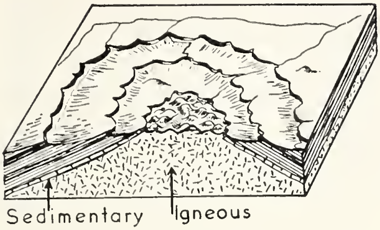


Fig. 12–15. Block diagram of a domed mountain whose igneous core has been somewhat exposed by erosion.

dome structures have recently been found in the Canadian Arctic.

15. Mountains from volcanoes. Volcanic cones may stand up as individual mountain peaks like Mount Popocatepetl in Mexico and Mount Etna in Sicily. Others may form in chains, probably along great fault lines, to build up volcanic mountain ranges from the floor of the ocean, as in the Hawaiian and Aleutian Islands. Still others may make individual contributions to the mass of great folded or faulted mountain ranges, as in the Andes Mountains of South America. Numerous examples of volcanic mountains are given in Chapter 11.

16. Complex mountains. Many mountain regions of the world have been formed through a combination of processes which makes it impossible to classify them accurately under any one of the four types described in the preceding paragraphs. Folding, faulting, doming, and volcanic eruption may have worked together in complicated fashion to produce these mountains, which are therefore called *complex mountains*. Some complex mountains consist entirely of igneous rocks, while still others are made of metamorphic rocks or highly disturbed sedimentary rocks. In many complex mountains several different classes of rock are found. Probably most mountains are to some extent complex. Examples include the Laurentides, the Long Range of Newfoundland, the Torngats of Labrador, the White Mountains and Piedmont Upland of eastern United States. The Piedmont is an example of a mountain region that has been eroded to a fairly level surface, and it is called a plateau by the inhabitants of the region. But its structure is not horizontal and therefore we do not classify it as a plateau.

THE LIFE HISTORY OF A MOUNTAIN

The life history of a domed mountain is very different from the life history of folded mountains or block mountains or volcanoes. But as with other land forms, there are certain characteristics that are typical of each stage of mountain development, regardless of type.

17. When mountains are young. During early youth, all mountains are growing, and their growth may be indicated by earthquakes, by volcanic eruptions, by the slow rise of rock strata, or by all of these events. Growth goes on for long periods of time, and as mountains grow they are immediately attacked by weathering and erosion. This causes young mountains to be both high and rugged, with sharp peaks, narrow valleys, and steep slopes on which landslides and avalanches frequently occur. Bare rock cliffs and ledges are common, and young mountains often reach high above snow line.

Because of the erosion that begins as soon as growth begins, even the youngest of mountains have their upper rock layers at least partly worn away. In domed mountains this may not yet expose the igneous cores. In young folded mountains the tops of the anticlines are also the tops of hills and ridges and are

likely to be the first layers to be stripped away. Examples of young mountains are the Himalayas, the Andes, the Alps, the Pyrenees, the Coast Range, the Rocky Mountains, the Sierra Nevadas, the Cascade Range, and the Hawaiian Islands. As often mentioned, the world's young mountains are found on the great fault lines that mark the "zones of weakness" in the earth's crust, where diastrophism and vulcanism are most active today.

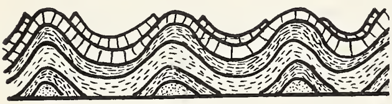


Fig. 12–16. The rock structure of the Jura Mountains of Switzerland, a young folded mountain region.

18. As mountains mature. In *maturity* the mountains have stopped growing, but weathering and erosion continue to wear down their surfaces. Peaks are greatly lowered, slopes become gentler, valleys become wider, and interstream areas are narrowed. Except in very high latitudes, mature mountains rarely reach beyond the snow line. Examples of mature mountains are the Appalachian Mountains, the White Mountains, the Laurentides, the Shickshock Mountains, the Black Hills, and the mountains of Scotland and Scandinavia.

19. Mountains grow old. When erosion continues for extremely long periods of time into *old age,* even mountains may be worn down almost to base level. The low rolling surface of an old mountain region is called a *peneplane.* Peneplane means "almost flat." It is spelled this way because pene*plain* would imply horizontal rock structure which an old mountain region does not have. Here and there on the peneplane —like the mesas and buttes on an old plateau region—there stand solitary rock masses known as *monadnocks.* These masses rise rather gently from the peneplane surface to modest heights that rarely exceed a thousand feet. Monadnocks are reminders of the once proud elevations of earlier days. Like buttes and mesas, monadnocks have strongly resisted erosion because of their durable rocks or their location in interstream areas of which they are the last remnants.

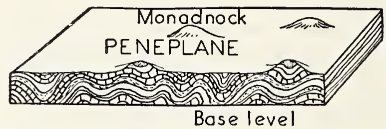


Fig. 12–17. An old folded mountain region or peneplane.

Peneplanes may be seen in many parts of the earth, but almost all of them have been raised by diastrophism and are no longer close to sea level. The development of a peneplane involves millions and millions of years, and it is no wonder that movements of the earth's crust occur during the late stages of peneplane formation or in the ages that follow. The rivers on raised peneplanes are said to be rejuvenated, or made young again. With newly increased slope, they begin a second cycle of life history, once more carving out young V-shaped valleys. But the level surface of the worn mountain rocks show unmistakably that the region had reached old age before being uplifted.

Raised peneplanes that have begun a second cycle of erosion are common in east North America. The uplands of northern New Brunswick, the Cape Breton Highlands, broad upland areas in western Newfoundland, the Torngats

and other mountains of coastal Labrador, the regions north and south of Lake Superior, and the Laurentians all come into this category. In the last example Mont Tremblant stands as a monadnock on the raised peneplane.

In the United States southern New England is a raised peneplane with Mount Monadnock on it.

20. Bedrock of plains, plateaus, and mountains. The horizontal rock layers of plains consist of gravels, sands, clays, and marls in varying amounts and in varying stages of consolidation or hardening. In recently formed plains, such as the outwash plain of Long Island, the floor of Lake Agassiz, the Atlantic Coastal Plain, or the flood plain of the Mississippi, the sediments are still likely to be loose rather than consolidated. In older plains, such as the interior Great Plains of the United States and Canada, the sediments are likely to be hardened into layers of conglomerate, sandstone, shale, and limestone. The rock layers of plains are rarely perfectly horizontal. Where porous layers outcrop between impervious layers, artesian formations like those of the Great Plains and the Atlantic Coastal Plain are created.

In plateau regions of sedimentary origin, the horizontal rock layers are sandstones, shales, limestones, and occasional conglomerates, as found in the Colorado and Appalachian Plateaus. In lava plateaus like the Columbia, the horizontal beds consist largely of basalts, rhyolites, and other fine-grained igneous rocks.

The rocks of mountain regions include folded, faulted, and tilted sedimentary rocks in such regions as the Appalachian Mountains and the block mountains of the Great Basin; igneous rocks such as granite in the Rocky Mountains and the Coast Range of western Canada, the Sierra Nevadas and the Adirondacks; metamorphic rocks such as gneiss and schist in the complex mountain regions of the Canadian Shield, western Newfoundland, the White Mountains and the Piedmont.

HAVE YOU LEARNED THESE?

Meanings of: physiographic region, plain, plateau, mountain, relief, butte, mesa, monadnock, peneplane, anticline, syncline

Diagrams and descriptions of: the structure of block, folded, and domed mountains; the life history of a plateau; the life history of a mountain region; anticlines and synclines

Origin of: the different classes of plains, plateaus, and mountains; mesas, buttes, and monadnocks

Examples of: the different classes of plains, plateaus, and mountains; young, mature, and old plains, plateaus, and mountains; the bed rock of plains, plateaus, and mountains

Differences between: a mature plateau and a true mountain region; a peneplane and a true plain; a hill and an anticline; a valley and a syncline

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) What is a physiographic region? (*b*) How do adjoining physiographic regions differ? (*c*) Name two specific examples of each kind of major land form in Canada. (*d*) What is the relation between major and minor land forms?

2. (*a*) In the older classification, what determines whether a region is a plain, a plateau, or a mountain? (*b*) What is the basis for classification in the newer system? Explain.

3. (*a*) What is relief? Explain. (*b*)

Define plain and plateau. (*c*) How does the newer classification of major land forms differ from the older one?

4. (*a*) In general, how do "regions of horizontal rock structure" originate? Give examples. (*b*) When do these become plains? Plateaus?

5. (*a*) How do marine plains originate? (*b*) Name two coastal marine plains in the United States. (*c*) How did the interior Great Plains originate? (*d*) Name regions of marine plains in Europe.

6. (*a*) What are lake plains? How did the great lake plain of southern Manitoba originate? (*b*) Describe two other lake plain areas in North America.

7. (*a*) What are alluvial plains? Name three types of alluvial plains and give a specific example of each type. (See Chapter 8.) (*b*) Name and give examples of two types of glacial plains. (*c*) Where are lava plains formed?

8. Describe the three stages of the life history of a plain. Give examples.

9. (*a*) What are fault plateaus? Give an example. (*b*) How was the Appalachian Plateau formed? Where is it? (See Figure 16–1.) (*c*) How are lava plateaus formed? Name and locate two great lava plateaus.

10. (*a*) Describe the three stages of a plateau's life history. Give examples. (*b*) Explain why the Catskills are called mountains in the older scheme of classification and plateau in the newer scheme. (*c*) Define butte and mesa.

11. Briefly explain how diastrophism and vulcanism make mountains.

12. (*a*) How do folded mountains originate? What are anticlines and synclines? (*b*) Name examples of folded mountains. (*c*) How does the position of these mountains support the theory of isostasy? (See Chapter 10.)

13. Describe the origin and characteristics of block mountains. Give examples.

14. Describe the origin and characteristics of domed mountains. Give examples.

15. How do volcanic mountains occur? Give examples. (See Chapter 11.)

16. (*a*) What are complex mountains? Name some. (*b*) Explain why the Piedmont Upland may be called a plateau and why we call it a mountain region.

17. Describe the characteristics of young mountains. Give examples.

18. Describe mature mountains. Give examples.

19. (a) Describe an old mountain region, explaining what a peneplane and monadnocks are, and how they form. (*b*) Why are peneplanes often found to be raised well above sea level? (*c*) Locate some raised peneplanes and monadnocks.

20. Discuss the kinds of bed rock found in plains, plateaus, and mountains.

GENERAL QUESTIONS

1. Compare the following regions as to kinds of rock, rock structure, and topography: (*a*) the Great Plains (of the western Prairies) and the St. Lawrence Plain; (*b*) the uplands of western Newfoundland and the Coast Range of British Columbia; (*c*) the Appalachian Mountains and the Appalachian Plateau; (*d*) southern New England and New Mexico's old plateau region.

2. How can an interior plain be identified as a marine plain?

3. How would a marine plain differ from a lake plain?

4. Mature folded mountains often have ridges with synclinal rock structure and valleys with anticlinal structure. (*a*) Draw a cross section diagram to show this. (*b*) Explain how these anticlinal valleys and synclinal ridges may have developed.

5. Why are alluvial fans likely to develop on the steep side of a block mountain?

6. Why don't we say, "Once a plain, always a plain"?

7. How can a monadnock be distinguished from a volcanic cone?

8. Folding, faulting, and vulcanism are all playing a part in the formation of the Coast Ranges of California. How do we know?

9. Make a contour map of an oval-

shaped domed mountain 40 miles long, 20 miles wide, rising from 3000 to 6000 feet. Select your own scale and contour interval.

10. Make a contour map of an old plateau with a butte and a mesa.

STUDENT ACTIVITIES

1. Taking field trips to see the rock structure and topography of local plain, plateau, or mountain areas

2. Visiting museum exhibits of the rocks, rock structures, and topography of plain, plateau, and mountain areas, and writing reports on these visits

3. Studying topographic sheets of plain, plateau, and mountain areas

4. Making models (of clay, plaster of Paris, etc.) to represent different types and stages of plains, plateaus, and mountains

5. Collecting pictures of features described in this chapter

SUPPLEMENTARY TOPICS

1. The Life History of a Domed Mountain
2. The Life History of a Block Mountain
3. The Life History of a Folded Mountain
4. Buttes and Mesas
5. Peneplanes in Eastern Canada
6. The Lake Superior Peneplane
7. Anticlinoria and Synclinoria
8. Pitching Anticlines and Synclines
9. Fault-Line Scarps
10. Salt Domes
11. Great Mountain Ranges
12. Mountain Climbing
13. National Parks That Feature Mountains
14. National Parks That Feature Plateaus
15. National Parks That Feature Plains

TOPOGRAPHIC SHEETS

1. *Young coastal plain:* Salmon Creek, Man. 54K6/E
2. *Young lake plain:* Emerson, Manitoba. 62H/3E
3. *Young plateau:* Soda Canyon, Colorado
4. *Mature plateau:* Kaaterskill, New York
5. *Old plateau:* Abilene, Texas
6. *Domed mountain:* Henry Mountains, Utah
7. *Block mountain:* Granite Range, Nevada; Fish Springs, Utah
8. *Folded mountain:* Mt. Robson, Alberta. 62H/3E
9. *Peneplane:* Worcester, Massachusetts
10. *Monadnock:* Mt. Monadnock, New Hampshire

SUGGESTIONS FOR FURTHER READING

Our Mobile Earth, by R. A. Daly. Scribner, New York, 1926.

Mountains; Their Origin, Growth, and Decay, by J. Geikie. Oliver Boyd, 1913.

Story of Mountains, by F. C. Lane. Doubleday, Garden City, New York, 1950.

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(*Also see list at the end of Chapter 5.*)

Chapter 13

WAVES, SHORE CURRENTS, AND SHORELINES

1. The making of shorelines. The struggle that goes on between constructional and destructional forces on the surface of the continents also takes place at their ocean boundaries. Here, at the shorelines where continents end and oceans begin, diastrophism and vulcanism vie with waves and currents in an endless contest that constantly changes the shape of the boundaries that separate the land and water areas of the earth.

A glance at a map of the world shows straight shorelines and crooked shorelines, shallow shores and deep shores, coastal plain shorelines and mountain shorelines, shores lined with sand bars and shores fringed by coral reefs. Each of these shorelines has a life history. In order to understand the present shape of a shoreline we must know—as with other land forms—how it originated and how it has been modified. There are many ways in which shorelines originate, and they will be taken up later in this chapter. All shorelines, however, no matter what their origin, may be modified by waves and shore currents. For this reason, we shall first see what effects waves and shore currents have on shorelines.

THE CHARACTERISTICS OF WAVES

2. Wind and waves. Except for the occasional waves caused by tides, earthquakes, and volcanic eruptions, practically all ocean waves are produced by winds. The connection between wind and waves is easily seen at the beach. On calm days waves are very small; on windy days they grow larger; in storms they may rise to mountainous heights.

The constant impact of the wind against the surface of the ocean causes the water to rise and fall in regular rhythmic movement. The stronger the wind and the greater the distance over which it blows, the greater is the rise and fall of the water. The highest point to which the water rises is called the *crest* of the wave; the lowest point to which it falls is called the *trough* of the wave (see Figure 13–1). The *height* of the wave is the difference in level between its crest and its trough. Great

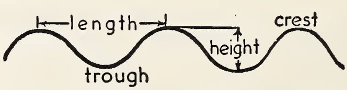


Fig. 13–1. The height and length of a water wave.

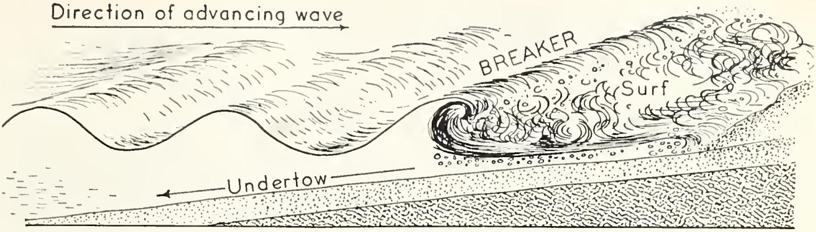


Fig. 13–2. The origin of breakers and undertow. In water that is too shallow for the wave, it scrapes the bottom and breaks. The water running back from the beach forms the undertow.

storm waves may regularly reach heights of 60 feet, and waves over 100 feet high have been reported.

The passage of a wave through water is like the passage of a wave through a rope. When a rope is snapped, each bit of the rope in its turn rises to a crest and then falls into a trough, and a wave is said to pass through the rope. But every bit of rope is still in the same place in the rope, having done nothing but rise and fall in a circular path, while delivering its energy to the next bit of rope. The same thing happens in a water wave. Each particle of water in the ocean stays in its place except for a circular bobbing motion, but the wave form is passed on through the rest of the ocean for great distances. As a wave passes through the water, many crests and troughs can be seen at once. The distance from one crest (or one trough) to the next is the *wave length*. Strong winds make longer waves as well as higher ones. Storm waves may be more than 500 feet long, and they may race through the water at speeds up to 60 miles an hour.

3. Whitecaps and ground swell. On very windy days, the tops of waves are often seen to be covered with white foamy spray. These *whitecaps* are formed when strong winds tear off the water from advancing wave crests. Whitecaps may be seen close to shore or far out at sea. *Rollers* or *ground swells* are huge waves that travel great distances from far-off storms to areas where the ocean is calm. Coming without warning, they may cause destruction and loss of life. It is not unusual to read of drownings and the capsizing of small boats when groundswells strike crowded beach resorts.

4. How breakers are formed. An advancing wave usually travels forward smoothly until it reaches water so shallow that the wave trough hits the sea bottom. At this depth the wave *breaks*, and the ocean water is actually hurled forward onto the shore. The line all along which the wave breaks is called the line of *breakers*. Swimmers at ocean beaches know that beyond the breakers they can bob up and down like a cork on the water with almost no forward motion, but *in* the breakers they are pounded by masses of water which may knock them down and drive them to-

Fig. 13–3. Surfriding on a line of breakers at Waikiki Beach, Hawaiian Islands.

Courtesy Matson Lines

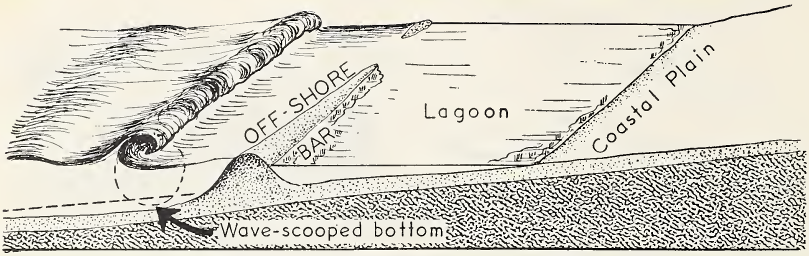


Fig. 13–4. The formation of an offshore bar and lagoon along a straight, shallow-water shoreline.

ward shore. At beaches where the ocean floor slopes very gently, breakers form far out from the shoreline. Surf-board riders, diving forward with a breaking wave at just the right moment, may be carried with the advancing water all the way onto the beach. At famous Waikiki Beach in Hawaii, such a ride may be a mile long.

WAVE ACTION IN SHALLOW WATER

5. Offshore bars and lagoons. Since breakers form as soon as a wave trough scrapes bottom, in regions of straight shorelines and shallow water a straight line of breakers forms at a considerable distance from shore. The higher the waves are, the sooner they scrape bottom and the farther out they break. The scraping of the waves against a sandy bottom has two effects. First, sand is scooped out of the bottom all along the line of breakers to form a small underwater "cliff." Second, the scooped-out sand is piled up just a short distance closer to shore to form an underwater sand "bar" parallel to the line of breakers.

As the action of the breakers continues for many years, the sand bar becomes wider and higher until it reaches sea level. Shore currents carrying sand from other parts of the coast may also help to build up the sand bar (see Topic 11). When the bar grows to sea level, its surface may be raised still higher by the action of wind and waves, and it may become a prominent feature of the shoreline. Sand bars of this type, running parallel to a straight shoreline and nowhere attached to it, are called *off-*

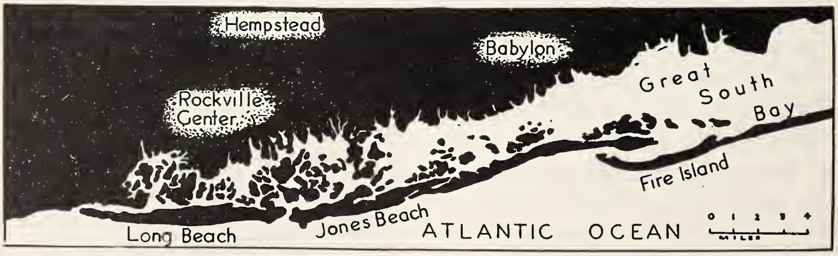


Fig. 13–5. Long Beach, Jones Beach, and Fire Island are offshore bars along the south shore of Long Island, N.Y. Great South Bay is a lagoon.

shore bars or *barrier beaches.* They may be seen wherever straight shorelines of shallow water occur.

Offshore bars protect the shallow areas behind them from winds and waves. These areas of quiet water between the offshore bars and the mainland are called *lagoons.*

6. Examples of offshore bars. The finest examples of offshore bars in the world are found along the Atlantic and Gulf coasts of the United States from southern Long Island to Texas. Many of the larger bars have become popular bathing resorts, as at Jones Beach on Long Island and Atlantic City in New Jersey. In eastern Canada, offshore bars (sometimes joined to the mainland) are found along the north shore of Prince Edward Island, and the east shore of New Brunswick. Less well-known, but also very extensive are the offshore bars of northern Ontario and Manitoba on the shores of Hudson Bay.

All offshore bars are low and very narrow in comparison with their length. Fire Island, off Long Island, is about 30 miles long but is less than a mile wide. Its greatest heights are those reached by the tops of its sand dunes—about 30 feet above sea level. One offshore bar, Padre Island, runs a distance of a hundred miles along the coast of Texas. The city of Galveston is built on another offshore bar off the Texas coast. Miami Beach in Florida is also located on an offshore bar.

WAVE ACTION IN DEEP COASTAL WATERS

7. Erosion by waves. Where the water is deep near the shore, waves may not break at all until they strike the land. When they strike, the breaking waves erode the shoreline in a number of ways. Mantle rock is torn away as easily as if

Fig. 13–6. Waves attack the headland of an irregular shoreline and drive much of the eroded material into the coves. Black Brook Cove, Cape Breton Island, Nova Scotia.

National Film Board, Canada

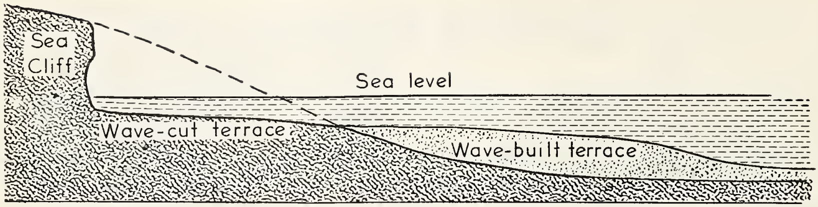


Fig. 13–7. The formation of sea cliffs and terraces is a result of wave erosion. The broken line shows the profile of the coast before erosion.

it were being dug with a steam shovel. Bedrock is split by water driven hard into cracks and fissures, or it is scoured away by the grinding action of sands and pebbles from the ocean floor.

Storm waves smash into sea coasts with forces amounting to thousands of pounds of pressure per square foot. In some cases, waves pounding rocky coasts have driven small boulders high into the air to smash lighthouse windows hundreds of feet above the surface of the sea.

8. How waves attack irregular shorelines. On irregular, zigzag shorelines, the areas that project into the water are called *headlands* or *promontories,* while the indentations of the shoreline are called *coves* or *bays.* Wave erosion against the headlands of a deep-water shore causes *sea cliffs* to form when the waves notch or cut away the rock at water level and the overhanging rock caves in. Sea cliffs are steeper in hard rock than in soft rock or in loose mantle rock.

As the waves drive deeper into the headland, level *wave-cut terraces* are worn at the base of the cliffs. The rock fragments eroded from the cliffs are used repeatedly by the waves as cutting tools until they are ground into small pebbles and sands. Some of these fragments are carried by the waves onto the shores of the quieter coves. As the fragments accumulate, they form *beaches* of pebbles or sand. Other fragments may settle in the deep water beyond the wave-cut terrace to form a fairly level deposit called a *wave-built terrace* (see Figure 13–7).

9. Sea caves, sea arches, and stacks. The rocks of a headland may vary somewhat in hardness. Where the rocks are less resistant, waves may dig in deeper than elsewhere to form short *sea caves* which are exposed at low tide. Waves may also wear right through vertical cracks in the sides of narrow headlands to form *sea arches* or small *natural bridges.* In the same way, the end of a headland may be completely separated from the rest of it to form a small rock island called a *stack.*

Fig. 13–8. A sea cliff and arch, Campobello Island, New Brunswick.

F. J. Alcock, Geological Survey of Canada

UNDERTOWS AND SHORE CURRENTS

10. Origin of undertows. When waves break on shallow shores, ocean water is hurled forward onto the beach to a con-

siderable distance past the shoreline and above sea level. This water immediately starts to roll back down the beach even as the next wave arrives. A person standing on the beach can feel the sand being sucked away from around his feet by the returning water. This water continues to move down the beach and along the ocean floor as an *undertow* pulling out toward the sea beneath the incoming waves. The stronger the waves become, the more water they hurl onto the beach and the stronger the returning undertows become. Undertows drag sand and clay from the beaches and carry them out to deeper waters. Strong undertows are a frequent danger to swimmers at many bathing beaches (see Figure 13–2).

11. Origin of longshore currents. Winds may blow from any direction at all, and only on rare occasions are the winds likely to be perpendicular to a shoreline. In most cases the winds blow diagonally, forming waves that break diagonally across the shoreline. The returning undertow from these waves, instead of running straight out to sea, forms a current running more or less parallel to the shoreline and in the general direction of the wind. Such a current is an "along-the-shore current," and it is called a *longshore current* or *shore current*. Shore currents may also be produced by winds blowing steadily in a direction parallel to the shoreline.

12. Deposits by longshore currents. On irregular shorelines, longshore currents carry sand and pebbles away from the wave-eroded cliffs of the headlands into deeper and quieter waters. Such waters occur in coves and bays and behind islands. On the shores of the coves the sediments may be deposited to form beaches; in open water they may form sand bars of many kinds. Some of the sand bars appear to grow out from the ends of the very headlands from which their sediments are derived. With one end attached to the headland and the other end in the open water across the bay or cove, these bars are called *spits*. Other bars grow completely across the

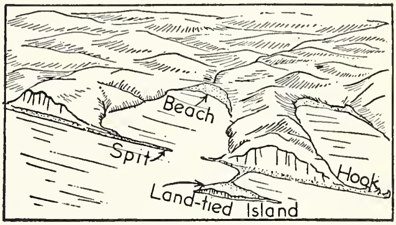


Fig. 13–9. The development of beaches and sand bars on an irregular shoreline. Sediments eroded from the headlands may be deposited at the ends of the headlands, or in sheltered coves, or behind islands.

mouths of bays to form *bay-mouth bars*. Still others grow from islands to the mainland to form *land-tied islands*. Waves or cross-currents may drive the ends of spits shoreward, forming spits with curved ends called *hooks*. The protected waters of the bays behind the bars become *lagoons*.

Sandy Hook in New Jersey, Rockaway Beach in New York, and Cape Cod in Massachusetts are famous examples of hooks which have grown many miles

Fig. 13–10. A hook or curved spit. Duck Point, Grand Traverse Bay, Lake Michigan. The mainland to which the hook is attached is at the left.

long and thousands of feet wide. As with the great offshore bars, winds and waves have combined to pile their sands many feet above sea level, making it possible to develop these areas into great beach resorts with permanent populations.

Longshore currents may also form along straight shallow-water coasts, where they assist the breakers in the building of offshore bars.

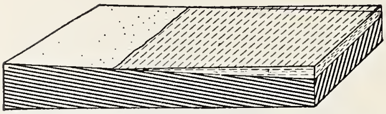


Fig. 13–11. The regular shoreline of a newly formed shoreline of emergence. Land is at the left, water at the right.

CLASSES OF SHORELINES

A number of years ago Professor Douglas W. Johnson of Columbia University introduced a classification of shorelines *according to their origin.* Professor Johnson's classification includes four main types of shorelines: shorelines of emergence; shorelines of submergence; neutral shorelines; compound shorelines. The origin of these types of shorelines and their modification by waves and currents will be discussed briefly in the following paragraphs.

13. Shorelines of emergence: origin. A coastal plain originates through the emergence of part of a continental shelf. A lake plain originates through the emergence of part of a lake floor. In each case, the shoreline formed "when the water surface comes to rest against a partly emerged sea or lake floor" is a *shoreline of emergence.* These shorelines are usually *very regular or straight* when first formed, since they represent the line of meeting of two flat surfaces. One, the water surface, is flat and horizontal, while the other surface, the plain, is flat and gently sloping. The smoothness of a sea or lake floor, as explained in the preceding chapter, is the result of its deposits of sediment.

14. Shorelines of emergence: life history. Since the gentle slope of a coastal plain or lake plain continues far out into the water, shorelines of emergence are areas of shallow water. As explained in Topics 5 and 6, offshore bars and lagoons soon develop along such shorelines. The bars are not continuous, for at irregular intervals the tides maintain openings through the bars called *tidal inlets.* Streams and winds carry sediment into the shallow lagoons from the land, while waves and tides carry in sand from the outside of the bar through the tidal inlets. Plants begin to grow in the shallowing waters, and the lagoons soon turn into salt-water marshes (see Figure 13–12).

By this time, however, the breakers have greatly deepened the sea floor on the outside of the offshore bars. Strong

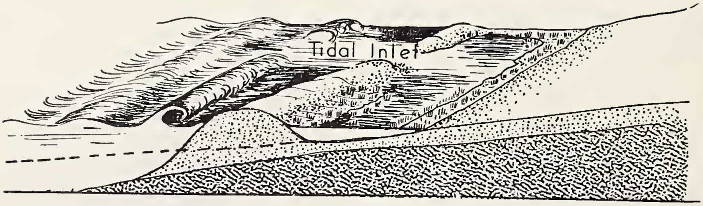


Fig. 13–12. As time passes, waves drive offshore bars inland, while sediment and vegetation fill the lagoons.

waves now strike the bars directly and slowly drive them into the lagoons. This process continues until both bars and lagoons are completely destroyed and their sediments swept out to deep water. Finally, the shoreline is almost where it started, but the sea floor is greatly deepened, and waves may now attack the mainland directly (see Figure 13–13).

Typical young shorelines of emergence may be seen on the coasts of northern Ontario and Manitoba, New Jersey, and Texas.

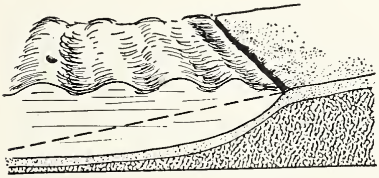


Fig. 13–13. Eventually both the bars and lagoons of a regular shoreline are destroyed by wave action.

15. Shorelines of emergence: folded mountains. Almost the entire west coast of North, Central, and South America from Oregon to central Chile has a comparatively straight shoreline produced by the emergence of young folded coastal mountain ranges. Narrow strips of coastal plain occur in places, but for the most part the ocean floor slopes steeply down to great depths not far from shore, and the coast is bordered by rocky sea cliffs carved out by the direct attack of the waves. Above sea level at short distances inland, numerous raised sea cliffs and terraces show that emergence of the land has been taking place steadily in recent periods of time.

16. Shorelines of submergence: origin. When the land bordering the sea or a lake is partly submerged, a new shoreline is formed. Such a shoreline,

U.S. Geological Survey

Fig. 13–14. Raised sea cliffs and terraces along the coast of California show that emergence of the land has occurred in recent geological time.

called a *shoreline of submergence,* is produced when the water surface comes to rest against a partly submerged land area. In contrast to shorelines of emergence, shorelines of submergence are almost always deep and very irregular. This is due to the fact that land areas have in most cases been dissected by weathering and erosion into steep rough surfaces in which hills and valleys alternate (see Figure 13–15). As the water of the sea rises over such areas, it enters far inland in the valleys to form *drowned valleys* or *bays;* it surrounds high hills to form islands; and it covers low hills to form dangerous *shoals* on the sea floor. The highlands between main river valleys project far out into the sea to form *peninsulas, headlands,* or *promontories.* Tributary valleys may also be partly drowned to become branches of the bays formed by the drowning of the main rivers (see Figure 13–16).

17. Shorelines of submergence: types. Shorelines of submergence vary considerably in different land areas. The south coast of Nova Scotia was formed by the partial submergence of a region of hilly topography. Its bays are short, narrow, and highly branched. Its waters are deep close to shore. Its islands and shoals are numerous and rocky. The coast of Scotland and the northwest coast of Spain are other examples of partly submerged mountain coasts.

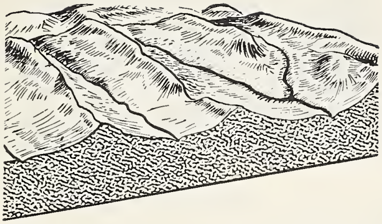


Fig. 13–15. A region of hills and river valleys before submergence. Submergence of such a region will produce an irregular shoreline.

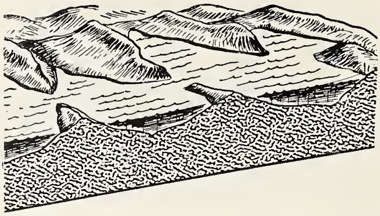


Fig. 13–16. The same region *after* partial submergence. The valleys have become bays, the ridges are headlands, and some hills are now islands.

Lighthouses are almost indispensable aids to navigation in these waters.

When a coastal plain is partly submerged, the bays that are formed are longer and wider than those of mountainous regions. The water close to shore is not as deep, nor are islands as numerous or as rocky. The Chesapeake Bay and Delaware Bay areas of the United States are examples of partly submerged coastal plains. Delaware Bay is the drowned valley of the lower Delaware River; Chesapeake Bay is the drowned valley of the lower Susquehanna River and its tributaries; the Gulf of St. Lawrence is in part the drowned valley of the lower St. Lawrence River; the Bristol Channel is the drowned valley of the lower Severn River in England. These drowned val-

Fig. 13–17. The estuary or drowned valley of the Hudson River at West Point, New York.

Fairchild Aerial Surveys

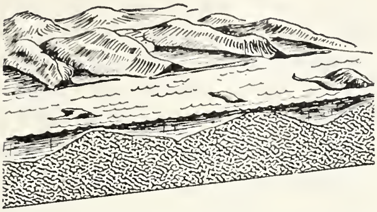


Fig. 13–18. A shoreline of submergence with its bays nearly closed by the growth of sand bars.

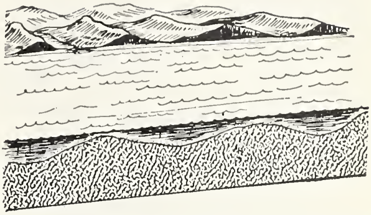


Fig. 13–19. A shoreline of submergence worn back by waves to the heads of the bays.

leys may extend many miles inland before reaching the portion of the river that is still above sea level. With their floors far below sea level, and the ocean filling their valleys from wall to wall, drowned rivers are much wider and deeper than normal rivers, and are known as *estuaries*.

18. Shorelines of submergence: life history. Since shorelines of submergence are generally deep and irregular, they soon develop the features described in Topics 8, 9, and 12 and Figure 13–9. Stacks, sea cliffs, sea caves, and sea arches are most common on rocky coasts like those of Maine and Scotland. On both mountain and plain shorelines, spits, hooks, bay bars, and land-tied islands are likely to be numerous. As time passes, the stacks and islands are worn away, the headlands are worn back, and bars completely enclose the mouths of the bays to form a straight shoreline and numerous lagoons (see Figure 13–18). But the straight shoreline of cliffs and bars continues to be attacked by waves until it is driven all the way back to the heads of the bays. The final result is a straight shoreline of deep water and high cliffs, cut through here and there by rivers entering the sea (see Figure 13–19).

19. Fiord shorelines. In many of the colder regions of the world, such as in Greenland today, glaciers of past ages had come down to the sea through valleys which, near the coast, were scoured out below sea level. When climates grew warmer and the glaciers melted away, the sea entered into and submerged the parts of the valleys that were below sea level. In some cases, sinking of the land helped to drown the valleys.

Fig. 13–20. Geirangerfiord, West Norway. A fiord is a partly drowned glacial valley. Its spectacular scenery includes high cliff-like valley walls and hanging valley waterfalls. Its deep waters can accommodate great steamers.

Norwegian Official Photo

These partly submerged glacial valleys along sea coasts are *fiords*. While bays are drowned river valleys, fiords are drowned U-shaped glacial valleys. Fiords extend farther inland and have deeper water than the bays of river-eroded mountain coasts. Down their cliff-like sides tumble the waterfalls of many hanging tributary valleys, making fiord coasts the most spectacular of all sea coast scenery. Fiords occur along the coasts of British Columbia, Labrador, Baffin Island, Greenland, and Norway.

20. Neutral shorelines. *Neutral shorelines* are shorelines whose main features do not originate from either emergence or submergence. They include a number of types which will only be mentioned here. Among these are the shorelines formed by deltas at the mouth of rivers like the Mississippi; shorelines of outwash plains like that of southern Long Island—almost identical with shorelines of emergence; shorelines of faulted mountain regions; shorelines of volcanic islands like Hawaii; and shorelines formed by coral growth as in Bermuda, east Australia, and the many coral islands of the Pacific Ocean.

21. Compound shorelines. Compound shorelines are shorelines whose main features are a combination of the features of two or more types of shorelines. To some extent, practically all shorelines are compound, but where one set of features is outstanding, the simplest classification is used. A good example of a compound shoreline is that of most of the Atlantic Coastal Plain. Formed by emergence of the continental shelf, the Atlantic Coastal Plain had a regular and shallow shoreline along which many offshore bars and lagoons developed. In recent geological times, however, the plain has been partly submerged to form the bays and irregular shoreline of the Chesapeake Bay, Delaware Bay, and Cape Hatteras areas. Because of a history of both emergence and submergence such features as offshore bars and spits are found in the same coastal areas.

22. The shorelines of lakes. Lake shorelines originate in the same ways as ocean shorelines. Irregular shorelines are formed by submergence; regular shorelines are formed by emergence. Where wave action and shore currents are strong enough, as in large lakes, all the features that they produce in the ocean are also formed in lakes. Shorelines of emergence may be seen along the south shores of Lake Erie and Lake Ontario. The Thousand Islands at the eastern end of Lake Ontario and the Georgian Bay region of Lake Huron are examples of irregular shoreline features formed by submergence.

CORALS

23. Growth of corals. Corals are tiny sea animals that live in colonies. Except in youth, the coral animals do not move about, but remain fastened to rocky sea floors in regions of warm, clear, fairly shallow water. Corals must have a water temperature of at least 68° F, and they

Ward's Natural Science Establishment, Inc

Fig. 13–21. Varieties of coral. ***Top row,* left to right: rose coral; many-pored coral; branching coral. *Bottom row:* brain coral; pink branching coral; organ-pipe coral; mushroom coral.**

do not grow at depths below 150 feet. Since corals do not move, they depend upon waves and currents to bring food to them. From the sea water, corals also extract dissolved lime to make the shells in which they live. The many different varieties of corals—the brain coral, the fan coral, the staghorn coral, and others —form an equally great variety of beautifully shaped colonies. When the corals die, the shells of their colonies remain, and other generations of corals grow up above them. These large accumulations of coral are *coral reefs*.

Although corals can grow only to the surface of the sea, waves may break the coral shells and pile them up above sea level. Fragments of coral form coral sands, and coral sands may become cemented together to form coral limestone.

24. Coral reefs. Coral colonies growing close to shore form coral reefs or *fringing reefs*. Such reefs occur along the coasts of Florida and Bermuda. The growth of a reef is most rapid on its ocean side, to which food is brought by waves and currents. As reefs grow oceanward, they may become *barrier reefs* which are separated from the mainland by broad lagoons of quiet water. The Great Barrier Reef of Australia is over 1200 miles long and up to 90 miles in width. Between it and the mainland is a broad lagoon known as the Inland Water Way.

25. Coral atolls. Coral atolls are narrow ring-shaped islands of coral limestone. They occur chiefly in the open waters in the middle of the Pacific Ocean. Wake and Midway islands are atolls of World War II fame, Eniwetok and Bikini islands are famous as sites of atomic bomb tests. Atolls are believed to represent the circular fringing reefs of sunken volcanic cones. There is usually at least one break in the coral ring of an atoll through which boats may enter. The lagoon inside the atoll offers valuable protection from winds and waves, and large atolls like Midway and Wake are important refueling bases for trans-Pacific airships.

United States Army Air Force

Fig. 13–22. Aerial view of an atoll in the South Pacific ocean.

HARBORS

26. The ideal harbor. Harbors are usually indentations in the shoreline which provide shelter for ships. A good commercial harbor must have a shoreline that is protected from wind and waves; it must have deep water close to shore, with small tidal range and good docking facilities; it must be easily accessible to both the ocean and an interior of commercial importance; it must not freeze over in winter.

27. Types of harbors. There are numerous types of harbors, but the requirements listed above are most frequently met in the submerged valleys or estuaries of coastal plain rivers. Many of the great harbors of the world, such as Vancouver, Halifax, New York, Philadelphia, Baltimore, San Francisco, London, Liverpool, and Hamburg in Europe, Shanghai in China, and Buenos Aires in Argentina are *submerged valley harbors*. (See Figure 13–23.)

Nova Scotia Film Bureau

Fig. 13–23. The submerged valleys of the Atlantic coast produce excellent natural harbors. Halifax with Dartmouth across the water and the Bedford Basin in the background.

Delta harbors are generally less suited to large ships, but on great rivers they may become of fair importance. Examples of delta harbors are New Orleans on the Mississippi, Calcutta on the Ganges River, and Para in Brazil on the Amazon.

Oslo, capital of Norway, has a *fiord harbor*. Vancouver, British Columbia and Boston, Massachusetts have harbors whose protection from the ocean is afforded by islands, making them *island harbors*. The harbors of Los Angeles and of Dover, England are artificial harbors protected from waves by man-made concrete breakwaters.

In general, irregular shorelines formed by submergence are far more likely to provide good harbors than are regular shorelines of emergence.

HAVE YOU LEARNED THESE?

Meanings of: offshore bar or barrier beach; lagoon; headlands; coves; shoreline of emergence; shoreline of submergence; fiord; estuary; atoll

Origin of: waves caused by wind; offshore bar and lagoon; sea cliffs, beaches, terraces, caves, arches, stacks; spits, baymouth bars, land-tied islands, hooks; shoreline of emergence; emerged folded mountain coast; shorelines of submergence and their bays, headlands, shoals, and islands; fringing reefs, barrier reefs, and atolls

History of: shoreline of emergence; shoreline of submergence; the Atlantic Coastal Plain's shoreline

Explanations of: wave height and wave length; whitecaps; ground swell; breakers; wave erosion; undertows; longshore cur-

rents; estuary; drowned valley; neutral shorelines; compound shorelines; coral growth; the requirements of a good harbor

Examples of: offshore bars; spits and hooks; shoreline of emergence; emerged folded mountain coast; shorelines of submergence (mountain and plain); fiord shorelines; coral reefs; atolls; harbor types

Identifying features of: a shoreline of emergence; a shoreline of submergence

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. What natural forces are involved in the shaping of shorelines? What must be known about a shoreline in order to explain its present shape?

2. (*a*) How does the wind cause a water wave? (*b*) Define a wave's crest, trough, and height. Illustrate these with a diagram. (*c*) Explain how water particles move when a wave passes through water. (*d*) Define the wave length. Show it in a diagram.

3. (*a*) What are whitecaps? (*b*) What are ground swells?

4. (*a*) How are breakers formed? (*b*) How does the motion of the water in the breakers differ from that in the waves beyond the breakers?

5. (*a*) What do the breakers do to the ocean floor? (*b*) Define offshore bar and lagoon. Explain how they form.

6. Name and describe examples of offshore bars. Of what use are they? How are they reached?

7. How do waves erode a deep-water coast?

8. (*a*) What are headlands and coves? (*b*) Explain the origin of sea cliffs, wave-cut terraces, wave-built terraces, and beaches.

9. Explain what sea caves, sea arches, and stacks are, and how they originate.

10. What is an undertow? How does it form?

11. What is a longshore current? Describe two ways in which such a current may originate.

12. (*a*) Explain what spits, bay-mouth bars, and land-tied islands are. (*b*) How are they formed? (*c*) How are hooks formed? Give examples.

13. What is a shoreline of emergence? How does it originate? Why is it so straight or regular when first formed?

14. (*a*) What are the characteristic features seen along a shoreline of emergence? (*b*) How are these features eventually destroyed? (*c*) Compare the original and final shapes of a shoreline of emergence. (*d*) Give examples of young shorelines of emergence.

15. What are the characteristic features of a newly emerged folded mountain coast? Name such a coast.

16. (*a*) What is a shoreline of submergence? How does it originate? Why is it almost always deep and irregular? (*b*) Explain the origin of bays, islands, shoals, and headlands. Why do bays often have branches?

17. (*a*) Explain how a partly submerged mountain region's shoreline differs from that of a partly submerged coastal plain. Name some examples of each. (*b*) What is an estuary? How does it differ from a normal river?

18. (*a*) What features are soon developed on a shoreline of submergence? Why? Give examples. (*b*) What eventually happens to such a shoreline?

19. Describe the origin and features of a fiord shoreline. Give examples.

20. What are neutral shorelines? Name some different types.

21. What is a compound shoreline? Explain how the Atlantic Coastal Plain's shoreline became "compound." What features show this?

22. How do lake shorelines originate?

23. (*a*) What are corals? Under what conditions do they grow? How? What is a coral reef? (*b*) What is coral sand? Coral limestone?

24. (*a*) What is a fringing reef? Give examples. (*b*) What is a barrier reef? Give an example.

25. (*a*) What is a coral atoll? How does it form? Give examples. (*b*) Of what value are atolls?

26. What are the requirements of an ideal harbor?

27. (*a*) Name several types of harbors, and give one or more examples of each. (*b*) Which class of shoreline offers the best harbors? Why?

GENERAL QUESTIONS

1. In what part of an offshore bar or spit are sand dunes most likely to form? Which way will they migrate? Why?

2. Why are sea caves unlikely to become very long?

3. In what way does wave erosion resemble erosion in a waterfall?

4. What features would be absent from the shoreline of the Atlantic Coastal Plain if it had not been slightly submerged after its formation by emergence?

5. Both shorelines of emergence and shorelines of submergence eventually acquire straight shorelines, according to the life histories described in Topics 14 and 18. How do they differ at this stage?

6. What seems to be the eventual effect of wave action on the shape of all shorelines?

7. Why don't coral reefs form in lakes?

8. What kind of rock should be found beneath the coral of an atoll? Why?

9. Why do submerged valley harbors on coastal plains have to be dredged frequently?

10. What disadvantages are likely to make fiord harbors of little value commercially? See Figure 13-20.

11. Make a diagram to show how artesian water can reach an offshore bar like Atlantic City.

STUDENT ACTIVITIES

1. Studying large scale wall maps of the continents in order to classify their shorelines as to origin

2. Studying topographic sheets that illustrate shorelines of emergence and of submergence

3. Making relief models (of clay, plaster of Paris, etc.) to illustrate shore forms described in this chapter, or to represent areas shown on topographic sheets

4. Making field trips to sea or lake shores to study the work of waves and currents and to observe shore forms

5. Collecting photographs of features described in this chapter

6. Collecting newspaper and magazine clippings that illustrate the occurrence and effects of waves, undertows, shore currents, and storms on sea or lake shores

SUPPLEMENTARY TOPICS

1. The Growth of Corals

2. The Origin of Coral Atolls

3. The Great Barrier Reef of Australia

4. A Comparison of the Great Harbors of the World

5. The Fiords of Norway and Other Countries

6. The Growth of Sandy Hook in Recent Years

7. The shoreline of eastern New Brunswick

8. Shore Forms along the Atlantic coast of Nova Scotia

9. The Characteristics of Ocean Waves; Record Waves

TOPOGRAPHIC SHEETS

1. *Shoreline of emergence and offshore bar:* Atlantic City, New Jersey; Fire Island, New York; Lake Como, Texas; Salmon Creek, Manitoba. 54K/6E

2. *Shoreline of submergence in hilly region:* St. Stephen, N.B. 21G/3E

3. *Shoreline of submergence on a coastal plain:* Montague, P.E.I. 11L/2W

4. *Spits and hooks:* Sandy Hook, New Jersey; Long Point, Ontario. 40I/9W

5. *Sea cliff:* Wellfleet, Massachusetts

SUGGESTIONS FOR FURTHER READING

Shore Processes and Shoreline Development, by D. W. Johnson. John Wiley & Sons, New York, 1919.

(Also see lists at the end of Chapters 5 and 35.)

Chapter 14

LAKES, RESERVOIRS, AND THE CONSERVATION OF WATER

INTRODUCTION

1. All about lakes. Because lakes are favorite places for summer vacations, they are perhaps the most familiar and most talked about of all earth features. "Pure, spring-fed mountain lake" say the advertisements. "Is it a natural lake?" asks the tourist. "So deep we can't find bottom," says a local authority. "Brrr, I'm standing in a cold spot," says a bather. "How did the lake get there?" asks the serious thinker. Other questions come to mind. "Does it have an outlet? Where does its water come from? What makes a salt lake? If a lake isn't natural, what is it? How is a lake formed?"

All of these questions can be answered by the student of earth science.

2. Bottomless lakes? People often proudly assert that the lake in their locality "has no bottom." If questioned further, they explain that no one has ever reached bottom with a line in certain deep spots in the lake. Finally they may admit that the line was no more, perhaps, than 50 feet long. To be accurate, then all they can honestly say is that the lake is more than 50 feet deep. Were a long enough line used, bottom would certainly be reached in any lake.

The deepest lake in the world, Lake Baikal in Siberia, is more than a mile deep. The deepest lake in North America, Crater Lake in Oregon, is almost half a mile deep. While the exact depth of any lake can be determined only by actual measurement, a depth of over 150 feet is unlikely for the smaller lakes in southern Canada. Even very large lakes can be comparatively shallow, as in the case of Lake Erie, which is only 210 feet deep. Lake Chad in Africa, with an area greater than that of Lake Erie, is only 20 feet deep during its wet season, and only 6 feet deep during its dry season.

3. Where the water comes from. The water in a lake may come from: (1) rain that falls directly into the lake; (2) the runoff from land surrounding the lake; (3) rivers that run into the lake; (4) the ground water, including the local water table and possible artesian formations. Lakes in humid climates receive a steady supply from the sources listed above, thus maintaining very uniform levels. Lakes in dry climates are likely to receive no ground water at all. Such lakes may rise considerably during the

rare rains, and then shrink to much smaller areas during dry periods. In this way Lake Chad varies in area from 50,000 square miles to 10,000 square miles!

4. Cold spots and warm spots. As explained in Chapter 6, lakes in humid regions are often below the level of the local water table, from which they obtain a steady supply of ground water. While much of this water simply seeps in slowly from the sides of the lake, some of it flows out in real springs on the bottom of the lake. Spring water is at about the same temperature all year round. In summer it is colder than the rest of the lake and forms "cold spots." In winter the spring water is warmer than the rest of the lake and forms "warm spots." These warm spots are slow to freeze over. Skaters and other winter-sports enthusiasts have been known to break through the thin ice at such spots when all the rest of the lake was safely frozen to a thickness of many inches.

Warm spots form in summer in quiet shallow areas which the sun has heated up more than the deeper surrounding waters.

THE ORIGIN OF LAKE BASINS

5. The shape of a basin. Lakes are usually defined as bodies of water that occupy closed depressions in the surface of the land. These "closed depressions," called *basins*, represent areas that are completely surrounded by higher land —just as a wash basin or bathtub is completely surrounded by its walls. Lake basins may be of almost any shape and any depth. A teacup set into a heap of sand might be comparable to the deep round basin of Crater Lake in Oregon. A saucer set into a level sandy beach might be compared to the large

U.S. Forest Service

Fig. 14–1. Aerial view of lake basins in Superior National Forest, Minnesota. The moraine dam separating the two large lakes in the foreground broke in 1926, causing the nearer lake to drop 30 feet in level, thus exposing the shallow part of its floor (white area in foreground) as a new "lake plain."

shallow basin of Lake St. John in the Saguenay district of Quebec. Lake Temiscouata has a deep, narrow trench-like basin, while Lake Timiskaming has a deep narrow basin of very irregular form.

6. The outlet. If water is poured into a wash basin or saucer, no water can run out until the basin is filled. In the same way, when rain or rivers or ground water pour into a lake basin, no water runs out until the basin is filled. Basins in dry regions may never fill up and may often be without any water at all. In humid regions, however, lake basins usually fill up until they overflow. The overflow takes place at the lowest point in the surrounding land, and the stream that runs out of the lake at this point is called its *outlet*.

The Niagara River is the outlet of

Lake Erie, the St. Lawrence River of Lake Ontario, and the Yellowstone River of Lake Yellowstone. As mentioned above, almost every lake in a humid region has an outlet. Anyone who has a desire for exploration may "discover" the outlet of his favorite lake simply by rowing or hiking around its shores. The armchair explorer may be content to find the outlet on a map of the region.

7. "How the lake got there." To explain "how the lake got there," you must know how the basin originated, for in humid regions basins must fill up. Lake basins may originate in a great variety of ways, many of which have already been described. Basins are formed by diastrophism, by vulcanism, by rivers, glaciers, winds, waves, currents, ground water, gravity, and even by plants and animals. All of these basins are "natural." Lake basins may also be made by man, in which case they are "artificial."

8. Reviewing the types of basins. The preceding chapters have described many methods of lake origin. Ground water forms *sink-hole lakes* in limestone regions. Rivers form *plunge-pool lakes* at the base of large waterfalls, *delta lakes* on the uneven deposits of deltas, and *oxbow lakes* on mature or old flood plains. Glaciers form *cirque lakes* and *rock basin lakes* in alpine regions. Continental glaciers form *kettle lakes* in moraines and outwash plains, and *drift-basin lakes* in unevenly deposited ground moraine. Both alpine and continental glaciers may form *moraine-dammed lakes* in valleys, and temporary *marginal lakes* like Lake Agassiz when the glacier prevents its own melt-water from flowing downhill. Vulcanism is responsible for the formation of *crater lake* basins.

Courtesy Swiss National Travel Office

Fig. 14–2. Marjelen Lake, a marginal lake formed between the Aletsch Glacier (center right) and its valley wall in the Swiss Alps.

Waves and shore currents form bars which cut off bays from the ocean and turn them into closed *lagoons* or coastal lakes.

9. Basins made by earth movement. As smooth as the continental shelf is, it nevertheless contains many broad shallow basins on its surface. When the shelf is *uplifted* to form a coastal plain, the deeper basins form lakes and the shallower basins form swamps. There are many examples of these coastal plain lakes and swamps on the young coastal plain of southern Florida. The largest of these lakes is Lake Okeechobee; the largest of the swamps is the great Everglades covering an area of about 4000 square miles of dense semi-tropical wilderness.

The Caspian Sea of Europe and Asia is the largest lake in the world. It is larger than all of our Great Lakes combined. Ages ago the Caspian Sea was part of the ocean, with which it was connected through the nearby Black Sea and Mediterranean Sea. But *warping* (uplift) of the land between the Caspian Sea and the Black Sea separated the two (see Figure 14–3) and made the Caspian Sea a lake, cut off from the ocean. The Black Sea and the Mediterranean Sea are still "arms of the sea." They, too, may some day be cut off from the ocean as was the Caspian Sea. Lake Champlain in New York State, which was once connected with the Gulf of St. Lawrence, a part of the Atlantic Ocean, was formed in this same manner.

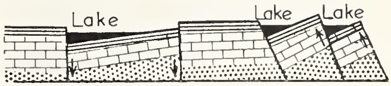


Fig. 14–4. The formation of lake basins by faulting. As shown by the arrows, both upward and downward movements of the crust may produce basins.

Still a third method by which diastrophism forms lake basins is faulting. Great blocks of the crust have sunk in many parts of the world to form the basins of lakes such as the Dead Sea in Palestine and the Great Lakes of Africa —including Lake Nyassa, Lake Tanganyika, and Lake Albert. In other cases, large blocks of the crust have been faulted and tilted, as in the formation of block mountains, to create basins of such lakes as Lake Warner and Lake Abert in Oregon.

10. How dams create lakes. Any mass of material that stretches across a river valley will block the flow of the river until the river reaches the lowest point in the mass. Such a mass of material is called a *dam*, and it changes a river valley into a lake basin. In order to get over the dam, the river must rise, overflowing its banks and flooding its valley. The lake formed by this overflow is as deep (at the dam) as the dam is high (see Figure 14–5), but becomes more and more shallow upstream. The lake extends upstream to the point in its bed

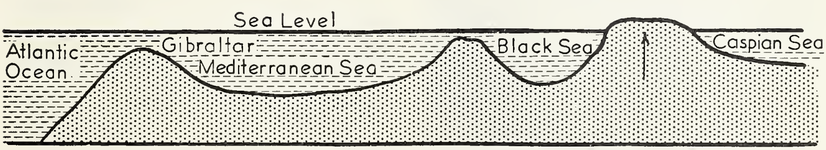


Fig. 14-3. The relation of the Mediterranean, Black, and Caspian seas to the Atlantic Ocean. The arrow shows how uplift of the sea floor cut off the Caspian Sea from the Atlantic.

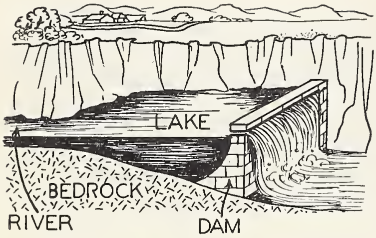


Fig. 14–5. How a dam converts a river into a lake. As the water rises to the level of the dam, it spreads over the low portion of the river valley, as if it were in flood.

that is *as high as the top of the dam.* The river is said to "back up" to this point. The higher the dam and the gentler the slope of the river, the longer the lake will be.

11. Dams made by nature. Dams across river valleys are made by a great number of natural agents. Glaciers may leave *moraine* dams. Volcanic action may leave *lava* dams, as at Lake Tiberias (Sea of Galilee) in northern Israel. Tributary streams may dam their own master streams with the *alluvial fans* deposited at the mouths of the tributaries as at Lake Tulare in California. Gravity causes *landslide* dams to form across steep-walled river valleys in many parts of the world. Winds may cause migrating *sand dunes* to dam up streams in sandy coastal areas. Beavers may make dams of small trees across streams, thereby forming ponds in which they can build their homes. Streams running through swamps have been dammed by the rapid growth of *swamp vegetation,* as at Lake Drummond in the Dismal Swamp of Virginia. In a few cases, large accumulations of tangled fallen trees have formed so-called *rafts* or *log jams* in large rivers, damming up the mouths of tributaries and turning them into lakes. The best known occurrence of this kind took place in the Red River of Louisiana and Arkansas during the last century.

National Film Board, Canada

Fig. 14–6. Beavers building a dam to convert a stream into a pond.

ARTIFICIAL LAKES

12. Why man makes dams. Man makes "artificial" lakes or *reservoirs* by building dams across river valleys. The great quantities of water stored in them may be used for irrigating dry farmlands, for providing a city's water supply, or for running hydroelectric generators. In regions where heavy rains cause floods in the river valleys, the great artificial lake basins provide storage space for the rain water, helping to prevent floods downstream from the dam, and providing deep water for navigation upstream from the dam. Then this stored water may be released slowly between rains, supplying the river below the dam with an even flow of water in dry weather as well as in rainy weather. Lakes are also made in order to provide recreational facilities such as bathing, boating, fishing, and skating.

While the basins of man-made lakes may be regarded as "artificial," the streams or rivers from which they receive their water supply are almost always "natural." Whether artificial or natural,

lakes may serve some or all of the same valuable purposes mentioned above. These may be summarized as irrigation, community water supply, water power, flood control, navigation, regulating stream flow, and recreation. Large lakes also have a moderating effect on the climate of their surroundings. Because of the relative slowness with which water warms up and cools off, lakes keep their surroundings cooler in summer and warmer in winter than they would be otherwise.

U.S. Bureau of Reclamation

Fig. 14–7. Hoover Dam was built across Black Canyon to dam up the Colorado River. Behind Hoover Dam is seen the beginning of 115-mile-long Lake Mead. Hoover Dam was once called Boulder Dam.

13. Dams for irrigation. Large numbers of dams have been built in the dry western regions of North America. While their principal purpose is to provide water for irrigation and community water supply, they also serve in most cases to provide power, to improve navigation, and to prevent floods. The most famous of these dams is Hoover Dam (formerly called Boulder Dam) on the Colorado River between Arizona and Nevada. Hoover Dam, built across narrow Black Canyon, is 726 feet high and less than a quarter of a mile long. It is the highest dam in the world. Behind it the Colorado River has been backed up into a lake 115 miles in length, with an average width of more than 2 miles. Lake Mead, as it is called, has the largest volume of any artificial lake in the world.

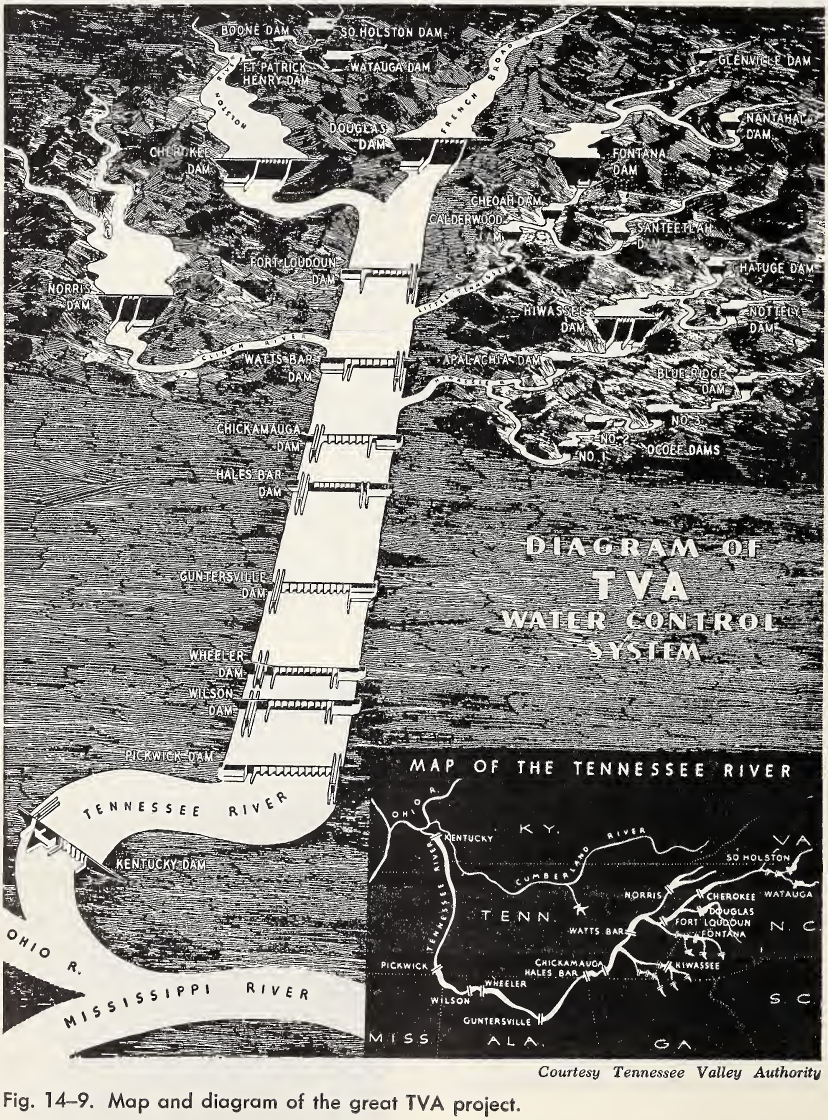
The largest concrete dam in the world is Grand Coulee Dam on the Columbia River in Washington. It is 550 feet high and nearly a mile long. Behind it lies the great reservoir called Roosevelt Lake, with enough water to irrigate over a million acres of land. Shasta Dam, 602 feet high on the Sacramento River in north-central California, forms a great reservoir used to irrigate the rich lands of the Sacramento Valley. Shasta is the world's second highest dam. Friant Dam on the San Joaquin River provides water to irrigate the San Joaquin Valley in central California. Other great irrigation dams include Elephant Butte Dam on the Rio Grande River in New Mexico, American Falls Dam on the Snake River in Idaho, Imperial Dam on the Colorado River in Arizona, Roosevelt Dam on the Salt River in Arizona,

Fig. 14–8. The earth dam constructed across St. Mary River, Alberta, for irrigation development.

National Film Board, Canada

Coolidge Dam on the Gila River in Arizona, Owyhee Dam on the Owyhee River in Oregon, and Pathfinder Dam on the North Platte River in Wyoming.

14. Dams for flood control. In regions of heavy rainfall, the main reason for damming up a river is flood control and flood prevention, while secondary reasons may be the improvement of navigation and the production of electric power. The greatest project of this kind in the world, in which twenty-six dams have formed a 650-mile long string



Courtesy Tennessee Valley Authority

Fig. 14–9. Map and diagram of the great TVA project.

of lakes, is the Tennessee Valley Authority (TVA) on the Tennessee River and its tributaries. The Tennessee Valley includes parts of the states of Virginia, North Carolina, Georgia, Kentucky, Tennessee, Alabama, and Mississippi. The largest dam, the Kentucky Dam, is 1½ miles long and 211 feet high. It is situated only 23 miles from the junction of the Tennessee and Ohio rivers at Paducah. As a result of the TVA project, the people of the Tennessee Valley are enjoying greater prosperity than ever before.

A vital flood-control project has been begun on the Missouri River, and fifteen of more than one-hundred major dams planned for this Missouri River Basin Project are already under construction or completed. Other great flood-control projects include the Denison Dam on the Red River in Texas and Oklahoma, the Canton Dam on the Canadian River in Oklahoma, and the Fall River Dam in Kansas. The Sacandaga Reservoir in New York State is another tri-purpose project, serving for flood control, water power, and the improvement of navigation on the Hudson River, of which the Sacandaga River is a tributary.

National Film Board, Canada

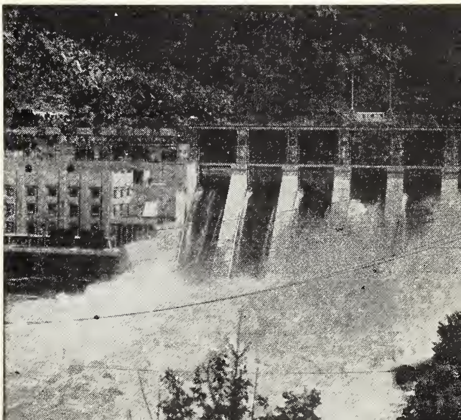
Fig. 14–10. Montmorency Falls, Quebec, are utilized for the production of hydro-electricity required by the textile industry.

15. Dams for navigation. Fort Peck Dam on the upper Missouri River in Montana is the largest dam in the world. Made of earth, it is 4 miles long, 250 feet high, and almost a mile thick at its base, tapering to a thickness of about 100 feet at the top. Not as high as Hoover Dam, Fort Peck Dam nevertheless contains about thirty times as much material. While built primarily for the improvement of navigation on the Missouri from Sioux City, Iowa to its mouth, it also serves for irrigation, flood control, and power. The same is true of Bonneville Dam on the lower Columbia River between Washington and Oregon. The Fort Peck Dam is part of the Missouri Valley Basin Project.

16. Dams for power. Dams are often built chiefly to obtain water for generating electricity. Among the dams of this type is the Beauharnois dam on the St. Lawrence, the Chats Falls and Des Joachims dams on the Ottawa River, and the Bersimis dam on the north shore of the lower St. Lawrence.

Fig. 14–11. Hydro-electric plant at Brilliant on the Kootenay River, B. C.

National Film Board, Canada



17. Dams for water supply. Many communities in all parts of the world obtain their water supplies by damming up streams. Almost the entire population of New York City is supplied with water by a great system that includes the Gilboa and Ashokan dams in the Catskill Mountain watershed, the Croton and Kensico dams in the Croton watershed, and the Rondout, Neversink, and Pepacton dams in its new Delaware River watershed. Los Angeles and thirteen nearby cities are supplied with water from the Colorado River at Parker Dam, 150 miles downstream from Hoover Dam and about 250 miles from Los Angeles.

In Massachusetts, Winsor Dam across the Swift River forms the great Quabbin Reservoir which supplies water to a large part of the population, including the residents of the city of Boston.

18. Dams for recreation. Many of the great reservoirs created by dams are today providing recreational facilities in addition to their many other uses. In some cases lakes are created specifically for their recreational values. Many of the lakes in New York and New Jersey's Palisades Interstate Park are artificial lakes. The Fanshawe dam across the Thames River in southwestern Ontario near London provides a recreation area as well as flood control on the Thames River.

THE DESTRUCTION OF LAKES

19. Lakes have short histories. As geological time is measured, lakes do not last very long. Shallow lakes may disappear almost within the lifetime of a human being. Deep lakes exist longer, but they too disappear in times much shorter than those in which the life histories of mountains or rivers are measured.

Lakes disappear because their basins are destroyed or because they lose their water. Basins are destroyed either by being filled in or by having parts of their surrounding high land worn down. Water may be lost by increased evaporation resulting from a change in climate.

20. Destruction by filling. Many natural agents may take part in the destruction of a lake basin by filling. Foremost among these agents are the rivers that flow into a lake, leaving all of their *rock sediments* deposited in the quiet waters of the lake, often in the shapes of deltas. Other lesser contributors of rock sediment are winds, waves, and gravity. Winds blow in dust and sand, especially in dry regions. Waves wash in materials from the shores. Gravity may cause landslides from the steep walls of mountain lakes.

Plants and animals may contribute *organic sediments* to the filling of a lake basin. Swamp grasses, ferns, mosses, and pond lilies grow and die in the shallow marginal waters of a lake, accumulating on the bottom and decreasing the size of its basin. Entire lakes are turned into swamps in time, and the large accumulations of *swamp plants* may be converted into beds of peat, and perhaps some day into coal. Fresh-water clams and other *lime-forming animals* also add to the organic sediments that help to fill the basin of a lake.

Wherever there are lakes, the processes of filling by rock sediments and organic sediments can easily be observed. Thousands upon thousands of oxbow lakes, glacial kettle lakes, and coastal plain lakes have been converted into swamps since their origin in recent geological time. An interesting case of filling by rock sediment is now taking place at Lake Mead. Worried engineers

E. P. Haddon, U.S. Fish and Wildlife Service

Fig. 14–12. Swamp growth and sediment destroying a small pond.

have calculated that material carried in by the Colorado River will completely fill this basin in about 200 years.

21. Destruction by erosion. Just as a lake basin may be created by the formation of a dam across a valley, so may a lake basin be destroyed by the removal of the dam or of any part of the surrounding wall of the basin. The wearing down of the dam or surrounding wall is most likely to occur at the outlet of the lake. As the outlet river runs out of the lake, it steadily erodes the low point in the rim of the lake basin at which it starts. *Erosion of the outlet,* as this process is called, is extremely slow, however, because the clear overflow waters of the lake contain no cutting tools for erosion. Almost invariably, lakes are filled with sediment long before their outlets are worn down low enough to completely destroy them.

22. Destruction by evaporation. Lakes may *receive* water from inflowing streams, from ground water, from direct rain or snow, and as runoff from surrounding land. Lakes may *lose* water by overflow through an outlet stream, by seepage through their beds, and by evaporation. (See Figure 14–13.) In humid climates, lakes rarely lose as much water by seepage and evaporation as they receive. Thus they overflow and always have outlets. In dry climates, on the other hand, lakes lose as much water by seepage and evaporation as they receive. Evaporation accounts for the greater amount of water loss. Lakes in dry climates therefore do not overflow and have no outlets. If the climate becomes dry enough, losses by evaporation may be so great that the basin dries out completely in a few days after each of the infrequent rains, and a permanent lake cannot exist. Such temporary lakes

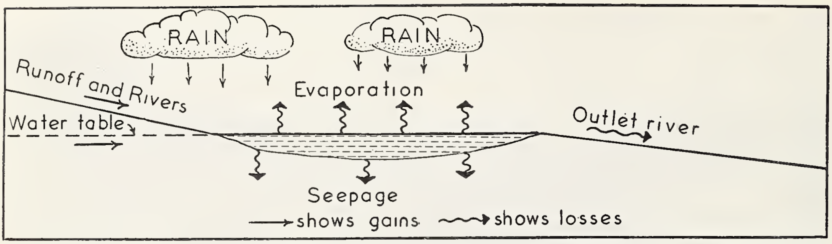


Fig. 14–13. Rain, runoff, and ground water are sources of lake water. The lake loses water through evaporation, runoff, and seepage.

are called *playas*, a Spanish word meaning "beaches."

Many lakes of long ago are known to have been destroyed by evaporation when their humid climates were changed to dry ones. The plains left by these lakes are covered with salt and other mineral deposits instead of with the fine soils of sediment-filled lake plains. In this manner Lake Bonneville in Utah and Lake Lahontan in Nevada disappeared many thousands of years ago, leaving Great Salt Lake and Pyramid Lake behind in the very deepest parts of their dried-up basins.

FRESH AND SALT LAKES

To most people, the story of lakes is incomplete until two puzzling questions are answered. How do salt lakes, such as the Great Salt Lake of Utah or the Dead Sea of Palestine, originate? How does an "arm of the sea" like Lake Champlain change into a fresh-water lake? Let us seek the explanations.

23. Fresh lake water. Fresh lake water is a mixture of rain, river water, and ground water. As such, it contains a small percentage of dissolved mineral matter carried into it by its river and ground water. The nature of this mineral matter depends on the nature of the rocks through which the river water and ground water have passed. Because lakes in humid climates overflow, as much dissolved mineral matter is constantly being carried out as comes in. Thus the lake always stays "fresh."

24. Fresh to salt-water lakes. In dry climates, lakes lose water so fast by evaporation that they have no outlets. During evaporation, the water escapes, but the dissolved minerals are left behind in the lake. Through the ages,

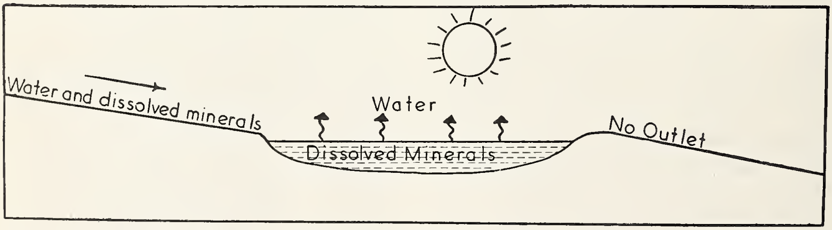


Fig. 14–14. The origin of a salt lake. Lakes in dry climates lose water through evaporation alone. Dissolved minerals are left in the lake, and in time the water becomes "salty."

rivers and ground water have been carrying water and dissolved minerals into these dry-climate lakes. Evaporation has removed as much water as has been brought in, but the dissolved minerals have been concentrated in the remaining water to make it "salty." The longer the lake exists under these conditions, the saltier it becomes. (Figure 14–14.)

The actual composition of the mineral matter in a lake depends on the rocks of its region. Great Salt Lake, a small remnant of the destruction of Lake Bonneville by evaporation, contains water with over 20 per cent mineral matter by weight. Most of this mineral matter is common salt. The waters of the Dead Sea in Palestine contain more than 24 per cent dissolved mineral matter, but only one-third of this is common salt, the rest being magnesium chloride. Lake Van in Turkey has waters that contain 33 per cent dissolved mineral matter! These waters are far denser than ocean waters, which have 3½ per cent of mineral matter.

Courtesy Salt Lake Chamber of Commerce

Fig. 14–15. Floating in Great Salt Lake, Utah. A person floats much higher here than in fresh or sea water, because of the much greater density of the waters of this lake.

The composition is quite different, making it obvious that the lake waters are not derived from the ocean. Since their waters are denser than the human body, people can float in them without any exertion whatever.

The production of minerals from the waters and deposits of salt lakes is a big industry today. Large quantities of common salt are extracted from Great Salt Lake. Borax and sodium carbonate are extracted from Searles Lake. Owens Lake and Mono Lake are also rich in valuable minerals, while Death Valley is laden in many places with the mineral deposits of lakes destroyed by evaporation. With the exception of Great Salt Lake, these locations are all in the desert region of California.

25. Why the sea is salt. When the ocean was formed by the first rains that fell upon the earth, the ocean contained nothing but fresh water. Since then, however, rivers from the lands have been carrying dissolved minerals into the ocean for millions and millions of years. Like a lake in a dry climate, the ocean loses water only by evaporation and has no outlets. As the river waters pour in and evaporate and return over and over again through the ages, more and more dissolved minerals are concentrated in the ocean waters. Lime and silica are removed by shell-forming animals, but salt and other soluble minerals remain to make the ocean salty. The older the ocean, the saltier it will become.

26. Converting salt to fresh lakes. Lakes that originate as cut-off bays or arms of the sea contain salt water when first formed. If, like Lake Champlain, they are in humid regions, they quickly fill up and overflow as rivers and rain pour into them. The continuous inflow of fresh water gradually washes out the original salt water, and in the course of

time such lakes become fresh. If the climate of Great Salt Lake ever becomes humid enough, it also will once again become a fresh water lake, as it was in the days of Lake Bonneville.

HAVE YOU LEARNED THESE?

Meanings of: lake basin, lake outlet, dam, playa

Origin of: lake basins of different types; artificial lakes; natural dams; salt lakes; the salt in the ocean; fresh lakes from salt lakes

Explanations of: sources of lake water; a lake basin; the outlet of a lake; cold spots and warm spots in lakes; what a dam is and how it determines the size of a lake; why man makes lakes; how lakes are destroyed; how lakes lose water; why lakes in dry climates have no outlets; why lakes with outlets stay fresh.

Examples and descriptions of: the different types of lake basins; irrigation dams; flood control dams; dams for improved navigation; dams for electricity, water supply, and recreation; salt lakes; lakes destroyed by evaporation; minerals extracted from salt lakes.

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. What are some of the questions about lakes that may arise in vacation resorts?

2. Discuss the origin and accuracy of the idea of bottomless lakes. Give some actual depth figures for famous lakes.

3. Compare the sources of lake water in humid and dry regions. How is the size of a lake affected by its climate?

4. (*a*) Can lakes really have cold spots? Explain. (*b*) Can lakes really have warm spots? Explain.

5. (*a*) What is a lake basin? (*b*) How are lake basins shaped?

6. Explain what the outlet of a lake is. Give examples.

7. Name some of the natural agents that form lake basins. When is a lake "artificial"?

8. Name ten kinds of lakes whose origins have been explained in earlier chapters. Name the agent by which each is formed.

9. Briefly explain, with examples, three ways by which diastrophism forms lake basins.

10. What is a dam? How does it make a lake? What determines the depth and length of the lake formed by a dam?

11. Name five or six ways in which natural agents may dam up rivers to form lakes.

12. (*a*) Name and discuss six or seven reasons why man makes lakes. (*b*) How does a large lake affect the climate of its surroundings?

13. (*a*) Name and locate several of the great irrigation dams of western United States. What other purposes may they serve? (*b*) Describe Hoover Dam or Grand Coulee Dam.

14. Name and locate several of the great flood control projects and dams of the United States. What other purposes may they serve?

15. Name and locate two dams built primarily to improve navigation. Describe one of them.

16. Name and locate several dams built chiefly to provide water power for making electricity.

17. What are the sources of water supply for Toronto? London (Ontario)?

18. How are dams used to increase recreational facilities?

19. What makes lakes disappear?

20. (*a*) Explain how a lake basin may be filled with rock sediment. (*b*) Explain how organic sediments may help to fill a lake basin. (*c*) Why are engineers worried about Lake Mead?

21. (*a*) Explain how a lake basin may be destroyed by the erosion of its outlet. (*b*) Why is this process so slow?

22. (*a*) List the ways in which a lake may receive and lose water. (*b*) Why do lakes in humid climates almost always have outlets? (*c*) Why do lakes in dry climates have no outlets? (*d*) What is a playa? (*e*) Name two ancient lakes that no longer exist, and explain why they disappeared.

23. Describe the composition of "fresh" lake water, and explain why lakes with outlets stay fresh.

24. (*a*) Explain how lakes in dry climates become salt lakes. (*b*) What determines the mineral composition of the water of a salt lake? Give some examples. (*c*) Why can people float more easily in salt lake waters than in the ocean? (*d*) What minerals are commercially produced from salt lakes?

25. How did the sea become salty? Explain?

26. How can a salt lake become fresh? Give one example.

GENERAL QUESTIONS

1. Why is a bottomless lake an impossibility?

2. Besides its effect on temperature, how else may a lake alter the climate of the surrounding land?

3. (*a*) Name four materials of which man-made dams may be composed? (*b*) Why must earth dams be thicker than concrete dams? What natural dams are made of materials comparable to those listed in your answer to (*a*)?

4. (*a*) Why are man-made dams thicker at the bottom than at the top? (*b*) How do natural dams usually achieve the same effect?

5. Why are so many dams necessary in the TVA project?

6. How do dams make navigation possible in a river that has rapids and waterfalls?

7. Crater Lake has no outlet, yet it stays fresh. How can this be explained?

STUDENT ACTIVITIES

1. Making relief models to illustrate the different ways in which lake basins originate. Making models of great dams

2. Studying topographic sheets illustrating different types of lake basins and the destruction of lake basins

3. Collecting photographs of different types of lakes

4. Collecting advertisements describing lakes as vacation resorts

5. Visiting and studying local lakes to determine their origin. Visiting local reservoirs and dams.

SUPPLEMENTARY TOPICS

1. Statistics of the World's Great Lakes
2. The Origin of the Great Lakes
3. Great Dams and Reservoirs of the World
4. The Tennessee Valley Authority Project
5. Navigation on the Tennessee River
6. Hydroelectric Plants
7. Alkali Lakes
8. The Local Water Supply System
9. The St. Lawrence Seaway Project

TOPOGRAPHIC SHEETS

1. *Crater lake:* Crater Lake, Oregon
2. *Coastal plain marshes:* Wolfville, N.S. 21H/1W
3. *Finger lake:* Skaneateles, New York
4. *Glacial lakes and swamps:* Madison, Wisconsin

SUGGESTIONS FOR FURTHER READING

World's Great Lakes, by F. C. Lane, Doubleday, Garden City, New York, 1948.

Lakes of North America, by I. C. Russell. Ginn, Boston, 1897.

World Almanac, New York World-Telegram.

Atlases.

(*Also see list at the end of Chapter 5.*)

Chapter 15

FLOOD PREVENTION AND SOIL CONSERVATION

1. What man has done. More than a billion years ago the rains and the rivers and the winds began their attacks on the surface of the earth. For countless ages, rivers have overflowed onto their flood plains, rains have washed soil from the hillsides, and winds have blown dust out of the semi-arid regions of the earth. These activities are natural processes and man accepts the fact that they must take place. But recent years have brought to us in the United States the unpleasant knowledge that damage from floods, rains, and wind has increased tremendously. We begin to wonder how much of the blame for the increase lies with us for the improper use of our natural resources. It is not only property damage that disturbs us. Even more alarming is the continuing loss of our "most precious natural resource," the soil on which the growth of all our food depends.

Today our country is thoroughly conscious of the need for preserving and protecting our natural resources. This has been largely the result of the conservation movement, which has sought to encourage the wise use of our natural resources. Many state and federal agencies have been created to deal with the problems of floods, of dust storms, of soil erosion, and of conservation of all forms of natural resources. All of these problems are interrelated and all are of vital importance to the future of the country. In this chapter we shall see why floods, dust storms and soil erosion occur naturally, how man has made them worse problems, and what he is now doing to control their destructiveness.

FLOODS AND FLOOD CONTROL

2. What river floods are. Rivers overflow their banks when they receive water faster than they can carry it away. The overflow is called a flood, and the flooded part of the river valley is called a flood plain. Young rivers have narrow flood plains, so their floods do not cover much territory. Mature and old rivers have broad flood plains, so their floods cover larger areas. In valleys with natural levees that are higher than the rest of the flood plain, the entire broad flood plain becomes flooded when the river rises above the levees. It is in such valleys that floods reach their greatest extent.

3. Floods from rain. The simplest and commonest cause of river floods is *heavy* rainfall. A single heavy downpour or cloudburst in the narrow valley of a young mountain stream may turn the stream into a violent torrent within a few hours. Floods of this type are known as *flash floods.* They are common in the Southwest and in the steep valleys of the Rockies and the Sierra Nevadas, where dry gulches or arroyos (ah *roi* ohs) briefly become filled with mighty rivers. Towns located at the bases of the mountains may suffer severely from flash floods.

Great rivers like the lower courses of the Missouri, the Ohio, and the Mississippi never have flash floods. Their floods are usually the result of many days of continuous rainfall over large portions of their great drainage basins. The larger the rainy areas, the higher the floods. As these floods move downstream, they may cover sections of flood plain far removed from the sources of the flood waters.

4. Floods from snow. The *rapid melting of snow* is the second most important cause of floods. When heavy winter snowfalls are followed by periods of warm weather called thaws, there may be as much water running into the rivers as during heavy rains. Thaws occur most frequently in the spring, of course, but winter thaws are not unusual. If thaws are accompanied by even light rainfall, floods are very likely to occur.

5. How much runoff? The occurrence of floods depends to a very great extent on the kind of ground on which the rains fall or the snows melt, as well as on the quantity of rain or melted snow. The percentage of runoff is much greater on bedrock and clay than on porous mantle rock; it is much greater on steep

National Film Board, Canada

Fig. 15–1. Sandbags used to make a dike in Winnipeg during the flooding of the Red River.

slopes than on level ones; it is greater on bare ground than on ground covered by vegetation. The greater the runoff, the greater is the likelihood of flood from a given quantity of rain. In winter and early spring there are many parts of the world in which the ground is frozen. *Frozen ground means ground in which all the pore spaces between rock particles are filled up by ice.* When rain falls or snow melts on such a surface, no water can seep in, and practically all the water runs off. In such cases even light rains or brief thaws may cause floods.

The percentage of runoff also varies with the heaviness of a rain. An inch of rain in a cloudburst or severe thundershower will cause far more runoff than an inch of slow steady rain on the same mantle rock surface. This is one reason why flash floods are likely to occur during short heavy downpours.

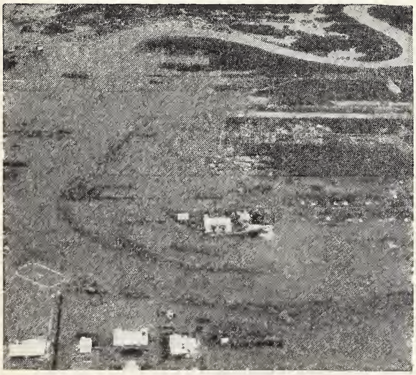
6. Other causes of river floods. There are other causes of floods which are much rarer and may be regarded as more or less accidental. The most common of these is flooding by *ice jams.* During severe winters, most Canadian rivers and many in the northern United States may freeze over to great thicknesses. In spring the ice breaks up or

"goes out," as it is called, and great cakes of ice float down the river. (In some communities it is traditional to try to guess the day on which the ice will go out.) Sometimes these cakes pile up at narrow or sharply curved places in the river bed, forming an ice jam or dam which ponds up the water behind it until it overflows its banks over extensive areas. Considerable damage may be done in the river valley upstream from the jam. But that may not be all. If the jam gives way suddenly, the river breaks through in a real flash flood downstream, and even greater destruction may result than in the slow rise of its waters behind the dam.

The *failure of a dam* is another important cause of floods. The famous Johnstown, Pennsylvania, flood was caused in this way. On May 31, 1889, after many days of heavy rains, a man-made earth dam on the Conemaugh River 2 miles above Johnstown suddenly gave way, and the entire reservoir burst down upon the city. More than 2200 people were drowned. Similar occurrences, usually less disastrous, have taken place in many parts of the world.

7. Flood seasons. Floods may come at any time of the year when heavy rains occur. In climates that have distinct rainy seasons, floods are certainly more likely to occur at that time than at other times. In the Pacific Coast region of the United States, floods occur most frequently in winter, because winter is the rainy season. One of the worst floods in California's history, brought about by exceedingly heavy rains, occurred during the winter of 1951–1952. In India, Burma, and other monsoon regions of the world, floods occur during the summer rainy season.

In Canada, floods are generally restricted to the summer half of the year, although flooding may occur in southern areas, even in winter, if there is a long period of warm weather and heavy rain. The worst floods normally follow the spring melting of the snow. At this time of the year, all rivers run above normal and if the snowfall has been



Royal Canadian Air Force

Fig. 15–2. Part of Winnipeg and St. Boniface during the Red River flood of May, 1950.

United States Army Air Force

Fig. 15–3. Flooded railroad yards and industrial section in Paducah, Kentucky. Paducah is at the junction of the Tennessee and Ohio rivers.

unusually high in the winter, the ground very wet in the preceding fall, or the spring thaw very sudden, floods may result. The Red River floods of 1950, which particularly affected Winnipeg were of this type.

Rivers in eastern Canada suffer badly from ice jams, and where there is a broad flood plain for the water to cover, bad floods may follow. The south shore tributaries of the St. Lawrence River are affected by these floods.

Short-lived floods are locally serious after summer and early fall storms, which are often associated with the dying stages of a hurricane and the heavy rains which accompany it. In Canada, southern Ontario is particularly susceptible to this type of flood. Water control may however remove the worst consequences.

The flood of the Missouri River in April 1952, following a year after the record disasters of the previous summer, once again emphasized the urgency of its flood-control program. In this great new disaster almost 2,500,000 acres of land and 123 cities and towns were flooded. Nearly 100,000 people were driven from their homes and over 40,000 people were engaged in fighting the flood. Forty-three railroads and 115 highways were closed, and property damage exceeded $300,000,000.

8. Living on flood plains. Like living near a volcano, living on a flood plain is perilous. Why do people live there? The answer is that flood plains offer many inducements to civilized man. For the farmer there are level, easily cultivated, and extremely fertile lands. For the businessman there are great consumer markets in the farm populations. For the industrialist, the great rivers and their flood plains provide easy water and rail transportation routes for raw materials and manufactured goods. For the laborer and mechanic and engineer there are jobs in the industries. In spite of the menace of floods, these people flock to the flood plains. Vast farm areas are developed and great cities grow up, especially at the junctions of rivers. Pittsburgh is at the junction of the Allegheny and Monongahela rivers; Kansas City is at the junction of the Kansas and Missouri rivers; St. Louis is on the Mississippi River 20 miles from the Missouri; Cincinnati is on the Ohio River; New Orleans is at the mouth of the Mississippi.

Because flood plains are so densely populated, tremendous damage to both life and property result when their rivers overflow. The greatest losses of life in all flood disasters have occurred on the crowded flood plains of China, where in 1887 nearly 1,000,000 people lost their lives on the Hoang-Ho River. In 1911 100,000 people lost their lives on the Yangtze River flood plain. Loss of life has been much less in southern Canada, but property damage has been enormous, running into many millions of dollars in the last century.

9. Man's share of blame. As stated at the beginning of this chapter, the causes of floods are largely natural. In what way, then, is man to blame for the increasing severity of floods? The answer lies largely in what man has done to the "condition of the ground." When land is covered by its natural growth of trees and shrubs and grasses, and its spongy mat of the decaying vegetation called humus (hyoo mus), it is an efficient absorber of rain and melting snow. When its natural cover is removed, the land loses much of its ability to absorb water, and the percentage of runoff is vastly increased.

U.S. Forest Service

Fig. 15–4. Woodland stripped of its trees by a forest fire—near Timber, Oregon.

Civilized man requires the use of forest timber, so he cuts down trees. Civilized man needs meat and dairy products, so he raises cattle that feed on grasses. Civilized man requires grains and fruits and vegetables, so he plows under natural vegetation and cultivates his crops. All of these activities are necessary for our existence, but they have been carried on so recklessly and foolishly as to bring down upon us a host of misfortunes. We have permitted our forests to be cut down without replacing them; we have allowed our cattle to overgraze their grasslands until the grasses were destroyed; we have cultivated land that proved to be too steep or too dry for farming, and then we have left it barren; we have raised crops that absorbed much less water than the native vegetation we plowed under; we have carelessly started fires that burnt down vast areas of forest and shrub and grass. All of these errors have destroyed natural vegetation, thereby increasing runoff and enlarging floods. It is only in recent years that we have come to understand our mistakes and to attempt to correct them.

Fig. 15–5. Artificial levees along the Atchafalaya River in Louisiana. Standing higher than the rest of the flood plain, they can be identified as artificial by their straightness and steepness.

Corps of Engineers, U.S. Army

10. Flood prevention. Flood prevention methods are of three different kinds. The first kind does nothing to reduce the quantity of water in a river, but simply tries to keep the water from overflowing onto the flood plain. This is done on mature or old flood plains by *building up their levees* with sand bags, concrete, or other materials. The built-up levees are called artificial levees (on the Mississippi and other rivers in the United States) or dikes (on the Rhine in Holland, the Po in Italy, and other rivers in Europe). One trouble with this method is that the levees may break. When they do, the river pours through in a flood far worse than a mere overflow. A second fault is that levees may have to be built higher and higher each year as river deposits raise the river bed. The higher the levees rise above the rest of the flood plain, the greater is the damage when the river does overflow.

The second kind of flood prevention attempts to reduce the quantity of water flowing in a river after heavy rains or thaws. It does this by building *dams*

across the headwaters and tributaries of the river, thus storing up the excess runoff in great reservoirs, and allowing only a small part of the runoff to flow into the river below each dam. Hoover Dam does this for the Colorado River. But in very rainy regions like the Tennessee Valley a single dam is not enough, for each part of the valley may collect enough rain to make its own flood. For this reason the TVA project includes twenty-six different dams along the Tennessee River and its tributaries.

The third kind of flood prevention attempts to reduce the runoff from a river's drainage basin by restoring the natural vegetation that man has destroyed. In the humid lands of the United States where the threat of flood is greatest, the natural vegetation is chiefly forest growth. Restoring the natural vegetation here means *reforestation*—the planting of trees to take the place of those that were cut or burnt away. But such a program would be incomplete if it did not also provide for future conservation of the forests by limiting the amount of timber to be cut and by providing for its replacement with young trees.

U.S. Forest Service

Fig. 15–6. Reforestation of a slope burned by a forest fire. Coeur d'Alene National Forest, Idaho.

DUST STORMS

11. Causes of dust storms. When strong winds blow great clouds of fine soil high into the air, a dust storm is said to occur. Dust storms can take place only when the soil is loose. To become loose, soil must be *dry and not held together by plant roots.* Small "dust storms" can be seen on dirt roads, on the bare parts of a ball field, or on a freshly plowed field, if there has been no rain for a number of days. When the soil is wet or held by the roots of grasses, shrubs, or trees, dust storms do not occur.

Between the Rocky Mountains and the 100th meridian lie the Great Plains of western United States and Canada. The natural vegetation of the Great Plains is short grass, making ideal cattle-grazing country. The rainfall of the

Courtesy Soil Conservation Service

Fig. 15–7. Native grasses provide the top-soil with complete protection from erosion. Near Dalhart, Texas.

Courtesy Soil Conservation Service

Fig. 15–8. A corn field late in November. The remaining roots and stalks, unlike native grasses, fail to protect the topsoil from being blown about by the wind.

region varies from a maximum of about 20 inches a year to a minimum of 10 inches or less in dry years. Wheat can be grown in this region in the rainier years, but it will die in the periods of drought. The native grasses, on the other hand, are adapted to the varying rainfall. They live through the droughts, and their thick roots hold the soil together even when it is dry. As long as the grasses remain, no dust storms of importance can occur.

12. The great dust storms. In the spring of 1934 the greatest series of dust storms in the history of the United States began on the Great Plains. The storms were caused by *extreme drought* and the *removal of natural grasses.* Nature was responsible for the drought. Man was responsible for the removal of the grasses. Here is the story.

The years following World War I saw a tremendous demand for wheat and beef all over the world. American cattle raisers allowed their great herds to overgraze the grasslands until the bare soils were exposed. American farmers, seeking more wheatlands, moved westward beyond the 100th meridian. They plowed under the soil-binding grasses of these grazing lands and raised wheat in a climate of uncertain rainfall. Thus, by overgrazing and out-of-place agriculture, the protective natural vegetation was stripped from the soil.

Things went well enough until 1934, although many fields had already been abandoned as the demand for wheat declined. In that year a severe drought occurred. The cultivated crops, unable to survive the lack of water, withered away. *But now there were no grass roots to hold the soil together.* The prevailing westerly winds, blowing over the Plains as usual, found a loose crumbling surface exposed to their action. Blowing vast clouds of precious topsoil off the face of millions of acres of once-productive farm land, the winds raised the dust high into the atmosphere and eastward across the country in a succession of "storms" that continued through the summer and into the fall. Wherever they went, the storms darkened the

Courtesy Soil Conservation Service

Fig. 15–9. A dust storm approaching Springfield, Colorado at 4:47 P.M. May 21, 1937. The town was completely darkened for a half hour.

skies, reaching even to the eastern seaboard cities of New York and Washington. In the East the storms were strange, weird spectacles, but in the Midwest they were disasters. Precious topsoil was lost forever. Coarse dust came down farther east to smother cattle and crops on farms in more humid regions. Even the interiors of buildings were invaded and damaged by the dust.

It was in this series of dust storms that the Dust Bowl was born. The Dust Bowl, so-named in 1934, includes parts of Texas, New Mexico, Colorado, Kansas, Nebraska, Wyoming, Montana, South Dakota, North Dakota, and Saskatchewan in Canada. The drought continued for several years, and more than 150,000 people were forced to abandon their farms and their homes. Many of these people became poor migrants, wandering from place to place in search of work. These were the most tragic victims of the dust storms.

Courtesy Caterpillar Tractor Co.

Fig. 15–10. Dust Bowl farmland in Texas ruined by the great dust storms of 1933–1936. Photo taken April 19, 1950.

13. Preventing dust storms. At the height of the drought in 1935, over 16,000,000 acres of land in the Dust Bowl were being stripped of their topsoil by the attack of the winds. By 1939 this vast area had been reduced to less than a million acres, and the rest of the land had been recovered—at least temporarily. This was due to the fact that the drought had ended and rainfall had returned to normal. Much of the recovery, however, resulted from the work of the Soil Conservation Service established in the year 1935 as a branch of the United States Department of Agriculture to meet the emergency.

The work of the Soil Conservation Service included two principal measures. The first was to *restore the natural grass vegetation* to millions of acres of abandoned farmlands. Nature assisted by providing more rainfall, and man assisted Nature by *contour plowing* to hold all the rain in the soil. As the grasses grew back, these lands were "returned to the cows and the sheep" for grazing. The second measure was to teach the remaining farmers in the more humid eastern parts of the Dust Bowl the *best way of cultivating their lands.* The farmers were also taught to use contour plowing, for if they could secure enough water for their wheat, their wheat would not wither, and dust storms would be less likely to occur.

Contour plowing is plowing along a contour line—a line that goes around a hill at a fixed level. This method of plowing forms terraces that hold the rain on the hillsides and give it time to soak in rather than run off. The old method of plowing up and down the hill created many miniature valleys through which much of the rain ran off (see Figure 15–11).

Another device used to help prevent dust storms is a "tree shelter belt" which breaks the force of the prevailing westerly winds. Such a belt, planned to extend the length of the Plains from Texas to North Dakota, was begun in 1936, and today it includes thousands of

Courtesy Caterpillar Tractor Co.

Fig. 15–11. Contour plowing on hilly land near Prescott, Washington helps to prevent soil erosion.

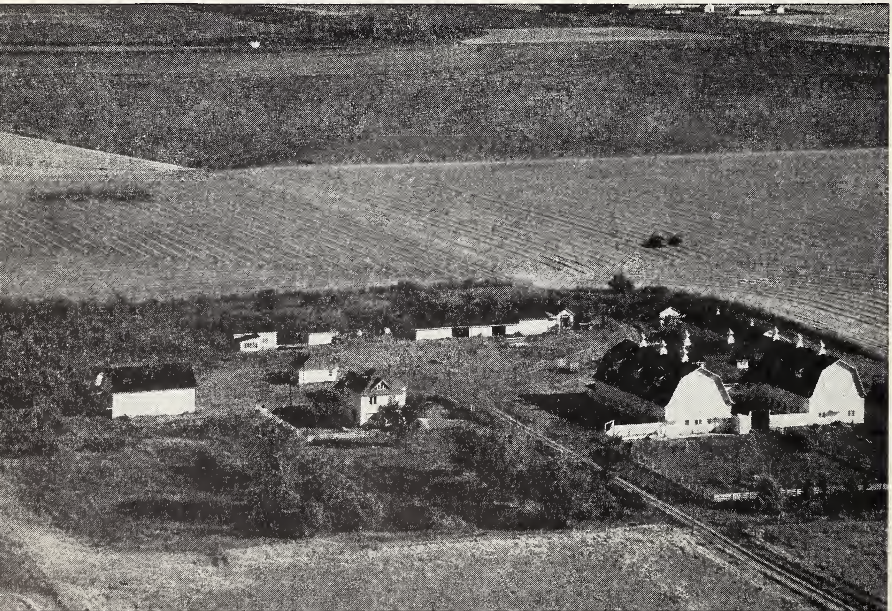
miles of tree rows. It is a co-operative effort of farmers and the federal government, under the Co-operative Farm Forestry Act of 1937. The use of trees as a windbreak is not a new idea, however, and many farms on the Plains had their own tree rows long before 1937.

SOIL EROSION

14. Is topsoil expendable? The removal of topsoil from the land by rain or wind is *soil erosion.* Why is soil erosion such an important problem? What does it matter that over three

Fig. 15–12. Windbreaks of young trees on farms near Moose Jaw, Saskatchewan.

National Film Board, Canada



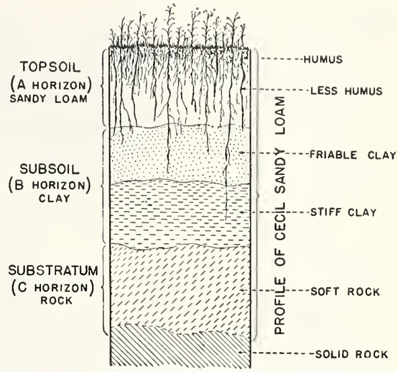
billion tons of topsoil are washed or blown off the surface of the United States each year? Can't the topsoil be replaced? Isn't there soil beneath it that is just as good?

The menace of soil erosion can be appreciated only if one knows what topsoil is and how it originates. A vertical section through a well-developed soil shows three distinct layers. The fairly loose, porous, usually dark top layer is the *topsoil.* Below this is a lighter, more compact layer called *subsoil.* Below the subsoil is the *parent material* from which the subsoil and topsoil are derived.

In residual mantle rock the *parent material* is simply the weathered bedrock. In transported mantle rock, the parent material may be a deposit made by glaciers, rivers, winds, or any other agent of transportation. *Subsoil* consists of sand, silt, and clay derived from the parent material often only after thousands of years of weathering of its rock minerals. *Topsoil,* too, contains sand, silt, and clay, but it differs from subsoil in many respects. Topsoil is richer in humus—the organic material from decayed plant roots and animal wastes. Topsoil contains the *soluble minerals* needed for plant growth. Bacteria and earthworms live in topsoil, helping to fertilize it and keep it porous. Topsoil is easily penetrated by essential air and water.

The qualities that distinguish topsoil from subsoil and make it fertile are acquired only after long periods of time. When the topsoil is swept away, it cannot be replaced within the lifetime of man!

15. Soil erosion by wind. The causes and remedies for soil erosion by the wind have already been discussed. During a dust storm, the wind strips the



Courtesy Soil Conservation Service

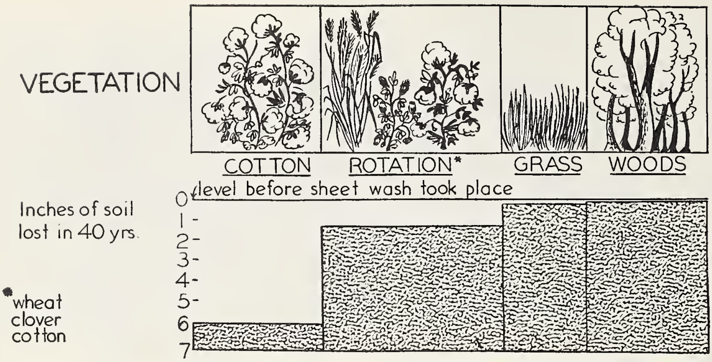
Fig. 15–13. Diagram showing a vertical section through residual soil. (A loam is a soil composed of sand, silt, and clay).

precious topsoil from dried-out lands wherever grazing and cultivation have removed the protective cover of natural vegetation. The best remedy for this situation is the restoration of natural vegetation.

16. Soil erosion by rain. Soil erosion by rain also occurs wherever the natural vegetation has been removed. In forest lands that have been stripped of their trees by timbering and forest fire, the cure is reforestation—the same cure that is needed to reduce runoff and prevent floods.

On cultivated lands, however, it is hardly possible to restore the natural vegetation. These lands must be kept cultivated in order to raise the crops essential to the very existence of the nation. Here, then, we have the problem of reducing soil erosion to a minimum while continuing to cultivate the soil.

17. Sheet wash and its prevention. There are two types of soil erosion by rain. One is called *sheet wash,* the other *gullying. Sheet wash* is the removal of



Based on Soil Conservation Service data

Fig. 15–14. Natural vegetation, such as grass or forest, gives almost perfect protection against soil erosion by sheet wash. When cotton is grown on sloping land, soil erosion is considerable. Rotation of wheat and clover with the cotton is of great value in reducing soil erosion.

thin sheets of soil from the entire area of even the most gently sloping farmland. It takes place whenever there is runoff from rain or melting snow. The removal of topsoil by sheet wash goes on so evenly that it can hardly be noticed. But sheet wash proceeds rapidly enough to strip a 6-inch layer of topsoil from moderately sloping cotton fields in 40 years (see Figure 15–14).

Sheet wash can be greatly reduced by contour plowing, strip cropping, and rotation of crops. (See Figures 15–14, 15–15, and Topic 19.) Contour plow-

Fig. 15–15. Strip cropping on the contours in Vernon County, Wisconsin. From the foreground up, the fields are planted with corn, grain (light color), alfalfa, grain, alfalfa.

Courtesy Soil Conservation Service

ing reduces sheet wash by reducing the runoff. In strip cropping, strips of dense rain-holding crops like alfalfa are made to alternate with the cotton, corn, or tobacco strips that are unable to absorb runoff because their plants must be so far apart (see Figure 15–14.)

18. Gullying and its prevention. Gullies are miniature river valleys that hold water only during rains. The origin of gullies was explained in Chapter 8. The formation of gullies on sloping farmlands is a more noticeable form of soil erosion than sheet wash, and it is more easily checked if promptly attended to. The usual procedure is to dam up the gully with boulders and brush (twigs, branches, leaves) or with boards. The dams not only check the flow of water, but also cause the deposition of any soil washed into the gully. Gullying is common in regions of steep slopes and heavy rainfall. Gullies will not develop if moderately sloping land is properly cultivated. If the slope of the land is greater than 15 feet per hundred, gullying may be impossible to control on cultivated land. It is therefore recommended that such land be restored to natural vegetation.

19. Soil depletion. When the same crop is grown year after year, the soil eventually loses the minerals needed for that crop. The soil is then said to be *depleted*. Soil depletion happens most rapidly with such crops as cotton and tobacco. There are two cures for soil depletion. One is the use of commercial *fertilizers* to restore the missing minerals. This expensive cure has been used in the depleted cotton and tobacco lands of the South. Another cure is the *rotation of crops*. Rotation is the planting of different crops on a particular plot

Courtesy Caterpillar Tractor Co.

Fig. 15–16. Gully erosion of sloping farmland. Here the slope is too steep for cultivation with ordinary farm crops which are unable to check the runoff of heavy rains.

Courtesy Caterpillar Tractor Co.

Fig. 15–17. The same field as shown in Figure 15–16. Gullying has been checked by growing *kudzu*, a clover-like plant which absorbs the rain and holds the soil together.

each year. For example (see Figure 15–14), wheat, sweet clover, and cotton may be rotated over a three-year period. Each one takes different combinations of minerals from the soil, so that no single mineral is removed too rapidly. Furthermore, the clover roots are rich in nitrates formed by their nitrogen-fixing bacteria, and it is often the practice to simply plow the clover into the soil in order to help fertilize it.

Soil depletion is not merely a matter of fertility. It has been proven that runoff and sheet wash are much greater in depleted soils than in fertile ones. The prevention of depletion and the prevention of soil erosion and flood go hand in hand.

HAVE YOU LEARNED THESE?

Explanations of: causes of river floods; flash floods; a thaw; frozen ground; why flood plains are populated; why man removes natural vegetation; flood control methods; the causes of dust storms on the Great Plains; the Dust Bowl; the prevention of dust storms; the origin and characteristics of topsoil; sheet wash; gullying; strip cropping; contour plowing; prevention of soil erosion by restoring natural vegetation; soil depletion; rotation of crops

Relations between: percentage of runoff and the kind of ground and rain; floods and seasons; removal of natural vegetation and the severity of floods; removal of natural vegetation and dust storms; soil depletion, soil erosion, and floods

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. Discuss the problem described in Topic 1.

2. What is meant by a river flood? Why are floods on old rivers more extensive than on young rivers?

3. (*a*) What is the commonest cause of river flood? Explain what a flash flood is, and how it occurs. (*b*) Explain how floods occur on great rivers like the Mississippi.

4. How does snow cause floods? When? What is a thaw?

5. (*a*) Give examples showing how the percentage of runoff varies with the kind of ground? (*b*) What is "frozen ground"? How does it help to cause floods? (*c*) How does the percentage of runoff vary with the kind of rain?

6. (*a*) Explain what ice jams are, and how they cause floods. (*b*) Explain how the famous Johnstown flood happened.

7. (*a*) Discuss the relation of floods to seasons in the Pacific Coast region of the United States. (*b*) Discuss the relation of floods to seasons in southern Canada east of the Rockies. (*c*) Explain why floods are more frequent in spring in Canada and the northern United States.

8. (*a*) Explain why people settle on flood plains. (*b*) Explain why great cities may be built on flood plains. Give examples. (*c*) Why is damage from the floods of mature rivers so great? Give examples

9. (*a*) Why is the removal of natural vegetation an important factor in causing floods? (*b*) Why must civilized man remove natural vegetation? (*c*) In what ways has he been unwise in the removal of natural vegetation?

10. (*a*) What are levees? How do they prevent floods? What are their disadvantages? Where are they used? (*b*) Explain how dams prevent floods. Give examples. (*c*) How does reforestation prevent floods?

11. (*a*) What two conditions are necessary in order for winds to cause dust storms? (*b*) Describe the location, climate, and natural vegetation of the Great

Plains. (*c*) How is it that dust storms do not ordinarily occur on the Great Plains?

12. (*a*) Explain how the natural vegetation of the Great Plains came to be removed after World War I. (*b*) Why did dust storms begin in 1934? (*c*) Describe the dust storms and their effects. (*d*) Describe the Dust Bowl and its people.

13. (*a*) What two steps did the Soil Conservation Service take to prevent future dust storms in the Dust Bowl? (*b*) What is contour plowing? What does it do? (*c*) What is the tree shelter belt? What is its purpose?

14. (*a*) What are the parent material and the subsoil? (*b*) Discuss the origin, characteristics, and importance of topsoil.

15. Summarize the causes and cure of soil erosion by wind.

16. (*a*) Where does soil erosion by rain occur? What is the cure in forest lands? (*b*) Why can't the same cure be used in farmlands?

17. (*a*) Explain what sheet wash is. (*b*) Explain how contour plowing reduces sheet wash. (*c*) Describe strip cropping. Explain how it reduces sheet wash.

18. (*a*) What is gullying? (*b*) How is gullying stopped? (*c*) When is it unwise to attempt to halt gullying on cultivated land? Why?

19. (*a*) What is soil depletion? What causes it? (*b*) How is soil depletion cured? (*c*) Explain what rotation of crops is and how it may improve the soil. (*d*) How is soil depletion related to soil erosion and flood?

GENERAL QUESTIONS

1. How may landslides cause floods?

2. After five successive days of rain, the runoff from a one-inch rainfall was much greater than it was on the first day of rain. Why?

3. Why do trees and native grasses absorb rain better than corn or cotton crops?

4. Why did the dust storms of 1934 and 1935 always blow eastward?

5. Why is the fertile soil that is blown off the Great Plains of no value where it lands farther east?

6. Soil erosion by rain is a problem even on the Great Plains. Why?

7. Why should runoff increase as soil is depleted?

8. How is loess related to dust storms?

STUDENT ACTIVITIES

1. Making models (of clay, plaster of Paris, papier maché, etc.) to illustrate contour plowing and strip cropping

2. Collecting photographs and clippings to illustrate floods, dust storms, soil erosion, and their prevention

3. Going on field trips to study local illustrations of soil erosion and its prevention

4. Performing experiments to determine the relation of runoff and soil erosion to the factors listed in Topic 5

SUPPLEMENTARY TOPICS

1. Famous Floods
2. The Dust Bowl
3. The Soils of Canada
4. Sharecroppers
5. Soil Minerals and Fertilizers
6. The Rotation of Crops
7. The Prairie Farm Rehabilitation Administration
8. The Maritime Marshland Rehabilitation Administration
9. The Canadian Forestry Service

SUGGESTIONS FOR FURTHER READING

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Deserts on the March, by P. B. Sears. University of Oklahoma Press, 1947.

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Chapter 16

THE PHYSIOGRAPHIC PROVINCES OF CANADA

INTRODUCTION

The preceding chapters tell the story of the origin of land forms. By this time the student knows how to explain the birth of mountains, the effects of the Ice Age, the types of volcanoes, the growth of offshore bars, the recession of waterfalls, the formation of underground caverns, and many other features of the landscape. The student can cite many examples of each of the land forms he describes, and can name the stages of their life cycles.

The preceding chapters have, nevertheless, left many gaps in the student's knowledge of the land forms of the entire surface of Canada. While many illustrations of land forms have been given, there are many parts of the country which have not been mentioned at all. What kind of land forms are found in the Hudson Bay Lowlands, the Coast Mountains of the Western Cordillera or in the Manitoba part of the Interior Plains? Where are the Rocky Mountain Trench, the Clay Belt and the Mackenzie Mountains? What rock structures and land forms will be seen in a trip through Nova Scotia, southern Alberta, or British Columbia? What physiographic regions will be passed through in a trip along the Trans-Canada highway from Cape Breton Island to Vancouver?

This chapter will answer these questions and may be considered as a brief (and very incomplete) guidebook to the land forms of Canada. When reading the chapter it must be remembered that although a great deal is known about the physiography in the south of the country, that in the north, there are still many tens of thousands of square miles which have never been seen by a geomorphologist, and that after there has been further arctic exploration, the boundaries of the regions may have to be changed. Canada is divided into seven *major physiographic divisions*. Each of these divisions is further divided into *physiographic provinces* or sections in which the bedrock and surface topography are fairly uniform throughout. To illustrate: the Western Cordillera is a major *division* which includes the Rocky Mountains, the Arctic Mountains, the Coast Mountains

and other *physiographic provinces* of Canada.

Each province or section is described briefly by giving its location, its rock structure, its surface topography, and a little about its industries. These descriptions, however, are just a beginning. Whole books have been written on the same subject, and some of these are listed in the references at the end of the chapter. They make interesting reading, especially for the would-be traveler.

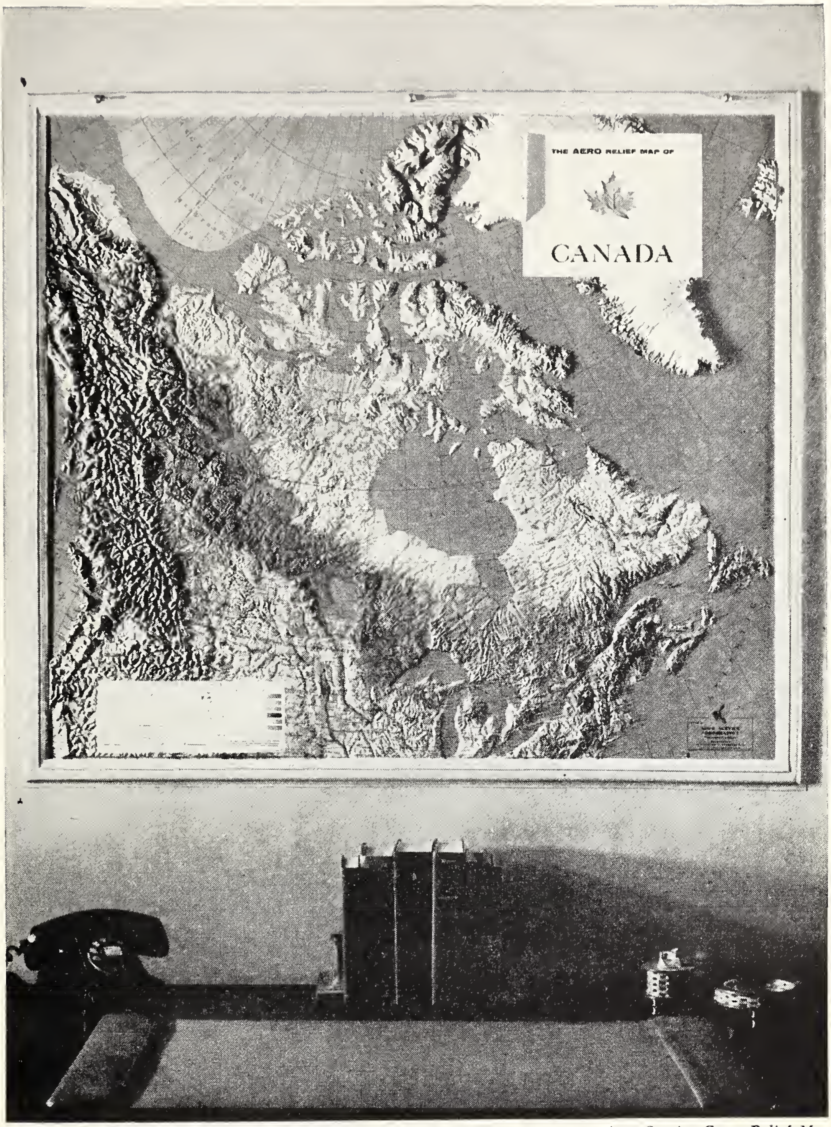
1. The Appalachian Upland Division. This major region extends from Alabama in the southeast of the United States to Newfoundland. It was once part of a high and complex mountain chain, but it has been eroded for so long in geological time, that in only a few places do mountains remain that are over 6000 feet high, and in eastern Canada the highest points are only a little over 4000 feet high. The area in Canada may be subdivided into five smaller regions.

(*a*) *Newfoundland.* The most easterly region is Newfoundland, which is formed of three peneplane surfaces, of which the highest is in the west. It is over 2000 feet high and forms the Long Range and other hills. It drops steeply as an escarpment to the Gulf of St. Lawrence on the west side. The middle surface is about 1300 feet high, and the lowest is in the east, and is between 500 and 1000 feet. Much lower than these rugged uplands are the major river basins, of which the Exploits River has formed the largest, by eroding softer rocks. The principal industry of this sparsely inhabited island is lumbering, fishing off the coast, and a small amount of mining, of which iron ore is the most important. Scenically it is an attractive island and when it is easier to reach from the mainland it may become an important tourist area.

(*b*) *Southern New Brunswick and Nova Scotia.* This is a complex area, with uplands separated by small lowlands which have developed on soft sandstones. These include the Annapolis Valley, the lowlands around Windsor and Truro, and the Vale of Sussex. Larger in extent, are the Atlantic Uplands which form most of peninsular Nova Scotia. It is a rolling region of low rock hills, with many lakes. Towards the northwest it rises, and ends as a scarp overlooking the Annapolis Valley. Higher hill ridges such as the Caledonia Hills and Cobequid Hills, are found elsewhere. In general the lowlands are settled and support farming, but the uplands have repelled settlement except along the coast.

(*c*) *The Lowlands of New Brunswick and Prince Edward Island.* This is a lowlying, gently undulating plain, which has developed on soft sandstone rocks, which are largely covered with glacial till. In New Brunswick, infertile soils support diminishing lumber resources, and there is a little coal mining. On Prince Edward Island the soils are more fertile and farming is important.

(*d*) *The Plateaus of North New Brunswick and Eastern Quebec.* This area extends from the Chaudière River, along the south shore of the St. Lawrence River to Gaspé and includes the northern third of New Brunswick. It is formed of flat upland plateau surfaces which have been partly dissected by deeply entrenched rivers such as the Restigouche and St. John rivers. In the interior of the Gaspé peninsula, the highest plateau forming the Shickshock Mountains has elevations ranging to more than 4100 feet. This area remains an important source of lumber for the



Aero Service Corp. Relief Map

Fig. 16–1. Relief map of Canada.

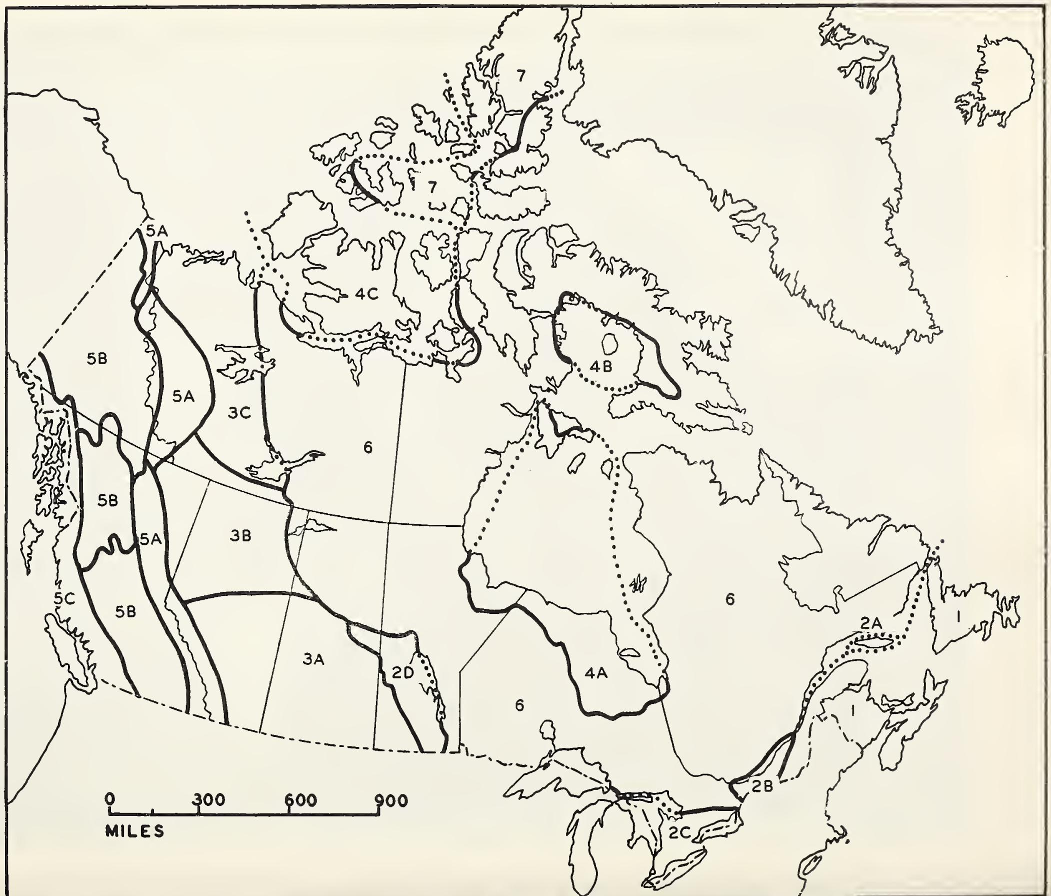


Fig. 16–2. The principal physiographic provinces of Canada.

1. The Appalachian Uplands.
2. The Interior Lowlands.
    2A. Anticosti Island
    2B. St. Lawrence Lowland
    2C. Great Lakes Section
    2D. Manitoba Lowlands
3. The Great Plains.
    3A. Prairies Section
    3B. Peace Section
    3C. Mackenzie Section
4. Northern Plains.
    4A. Hudson Bay Lowlands
    4B. Foxe Basin Lowlands
    4C. Western Arctic Section
5. The Western Cordillera.
    5A. Eastern Mountains
    5B. Interior Plateaus and Mountains
    5C. Western Mountains
6. Canadian Shield.
7. The Innuitian Division.

pulp and paper mills, and has a developing mining industry.

(*e*) *The Eastern Townships.* This region in southern Quebec is formed by parallel hill ridges of which the Sutton (with peaks over 3000 feet), Stoke, Border and Notre Dame ranges are the most important. Between the hills flow rivers in wide valleys. In places the valleys are blocked by glacial material, or have been glacially overdeepened to form long lakes such as Lake Memphremagog. All the valleys are choked with sand left by glaciers at the end of the Ice Age. This area is predominantly a farming region today, although the asbestos industry around Thetford-Black Lake, locally lumbering, and the textile industries in the many small towns are also important.

2. The Interior Lowlands. This division in Canada is split into four separate units, although the two westerly sections are connected through the Midwest of the United States. All these physiographic provinces have in common, sedimentary nearly horizontal rocks, of which limestone covers the greatest area. Over the rocks are glacial, marine and lake deposits of sand and clay which were left by the ice sheet and water bodies, at the close of the Ice Age.

(*a*) *Anticosti Island.* The most easterly division, Anticosti Island, is separated from the St. Lawrence Lowlands by 300 miles of the lower St. Lawrence River. The island slopes to the south with a scarp on the north side. The lower levels are covered with marine gravels laid down when the sea was higher than today. The island is used solely for lumbering.

(*b*) *The St. Lawrence Lowland.* This area has formed on the weaker sedimentary rocks which exist between the Canadian Shield on the north, and the Canadian Appalachians on the south. The lowland extends from Quebec to Brockville up the St. Lawrence River, and to near Renfrew along the Ottawa River. It is a flat plain, covered with glacial, and marine clays and sand. The plain, which nowhere has an elevation above 500 feet, rises gently towards Quebec, the St. Lawrence River becoming entrenched into the surface. Above the plain, stand the Monteregian Hills, including Mount Royal, with Montreal at its foot and on the lower slopes. These hills are formed of intrusive igneous rocks which are much younger than the other rocks in the plain. The lowland is primarily a farming area except where the sands are very extensive and the less fertile soils are left under poor forest. In addition the lowland has a number of important manufacturing and administrative cities such as Quebec, Three Rivers, Montreal and Ottawa. Although there is only a small area of forest left in the lowland, the nearby lumber and hydro-electricity

Fig. 16–3. Cross section through southern Canada, approximately from Halifax to Vancouver Island. *Part I:* from the Atlantic Ocean to the Canadian Shield.

from the Canadian Shield, provide the material and power for an important paper industry.

(*c*) *The Great Lakes section.* This area is that part of southern Ontario which lies on the south side of the Canadian Shield. It includes the Ontario peninsula between Lake Huron, and Lake Erie and Ontario, Manitoulin and smaller islands in Lake Huron. The underlying rocks are limestones and other sedimentary rocks, but they only appear on the surface in the east, near Kingston, and where they outcrop to form the Niagara Escarpment. This scarp enters Canada from New York State below the Niagara Falls, and continues westwards to pass south of St. Catharines and Hamilton, and then north to Collingwood and the Bruce Peninsula. Elsewhere the rocks are covered by glacial clays and sands. The glacial clay is often moulded into drumlins, particularly in the Peterborough area, where there is one of the largest drumlin fields in the world. The glacial sands are found in the moraines that run north of Lake Ontario, while the lake clays are commonest near lakes Huron and Ontario. The varied soils combined with one of the best agricultural climates in Canada have helped produce a rich farming countryside. In addition, although poor in minerals, (rock salt, and a little petroleum and natural gas being the only ones of significance) the Great Lakes section is the centre of the manufacturing region of Canada with many industries including iron and steel production at Hamilton, and the automobile industry in a number of cities.

(*d*) *Manitoba Lowlands.* This area is in some respects similar to southern Ontario. It is bounded by the Manitoba escarpment on the west and the Canadian Shield on the north and east sides. The lowest part of the plain is occupied by Lake Winnipeg, Lake Winnipegosis, Lake Manitoba, and many smaller lakes. These lakes are the surviving remnants of the glacial Lake Agassiz which once covered all the lowland. Silts and clays deposited in this lake now cover the southern part of the region and help produce the fertile farming area of the Red River Valley. Further north between the large lakes, the soils are thinner and poorly drained. Much of this area is swamp or under poor forest. The mineral resources of the lowlands are few.

3. The Great Plains. The division of the Great Plains forms a belt 1600 miles long and 200 to 500 miles wide, between the Canadian Shield and the Western Cordillera. Throughout much of geological time this division has been an area of sedimentation between the Canadian Shield to the east which was being reduced by erosional forces, and the rising mountains in the west. The Great Plains may be divided into three sections. All three are formed of similar nearly horizontal, sedimentary rocks, which have been covered with glacial clays and sands as a result of the Ice Age.

(*a*) *The Prairies Section.* This area is roughly the same as the settled section of the Prairie Provinces west of Manitoba Lowland. The Plains slope towards the northeast from nearly 4000 feet at the edge of the foothills of the Rockies to 1500 feet in Manitoba. The surface of the plains is flat (when it may be the floor of a former lake) or rolling (when it is probably glacially formed). All the large, and many of the small rivers, are incised 200 to 300 feet below the general level and flow in wide steep-sided valleys. In the southern part of the Prairies, some of these

deep valleys mark the channel of former rivers which flowed along the edge of the ice sheet. They are now dry or occupied by small alkaline lakes. Above the general level of the Plains are flat-topped hills, which are remnants of a former higher surface which has nearly been destroyed by erosion. These hills include the Cypress Hills on the border of Alberta and Saskatchewan, Wood Mountain in southern Saskatchewan, and Turtle Mountain in southern Manitoba. Also rising above the general Prairie level are the hills that form the Manitoba escarpment which overlooks the Manitoba Lowland; locally these are known as Pembina, Riding, Duck, and Porcupine mountains. The Prairies Section was formerly natural grassland in the south, and parkland—grassland with groves of trees—in the north. Today it is one of the principal wheat-growing areas of the world, while beneath the surface, particularly in Alberta, are great reserves of coal, petroleum and natural gas.

(*b*) *The Peace Section.* This section is drained by the Peace River, Hay River and southern tributaries of the Liard River. The region is directly comparable to the Prairies Section except that it lies wholly within the forest belt with the exception of a small area of natural grassland on the Peace River. Many of the rivers, including the Peace River, are deeply entrenched into the plain surface. Above the plain rise a number of hills, including the Watt Mountains and Caribou Hills of northern Alberta. North of the hills the land is much lower towards Great Slave Lake. In the southwestern part of the Peace section there is settled farmland, but elsewhere the population is mainly Indian. It is believed that petroleum (in addition to the Tar Sands near Fort McMurray) is present in some areas but these resources are still undeveloped.

(*c*) *Mackenzie Section.* This area, covered by subarctic forests is generally flat and badly drained with many small lakes. The bedrock rarely appears on the surface as it is buried under thick glacial and river deposits. Occasional low hills are found, such as the flat-topped Horn Mountains. Two of the largest lakes in the world, Great Slave Lake and Great Bear Lake, are found in this section.

4. The Northern Plains Division. This major division is composed of three separate sections, the *Hudson Bay Lowlands*, the *Foxe Basin Lowlands*, and the western *Arctic Plains and Plateaus.* The first two sections are flat, monotonous limestone plains under 500 feet in elevation with no conspicuous landforms. The lowlands were submerged by the sea at the end of the Ice Age when the land was lower than at present. As the land rose, the sea retreated, leaving innumerable beach ridges with lagoon-lakes dammed behind them. Everywhere there are shallow lakes, marshes and muskeg. In the northern

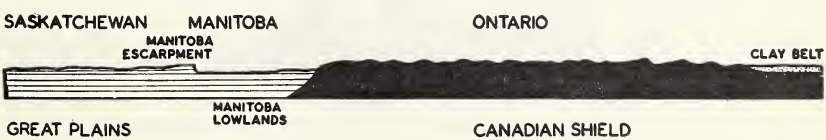


Fig. 16–4. Cross section through southern Canada, approximately from Halifax to Vancouver Island. *Part 2:* from the Canadian Shield to the Great Plains.

part of the Hudson Bay Lowlands and in the Foxe Basin Lowlands, the plains are covered with frost-shattered limestone plates which form broad rock deserts. Close to sea level where the water table is at the surface, marsh and tundra vegetation are found.

The Western Arctic Section is rather different from the other two regions. It is also developed largely on limestone but other sedimentary rocks are present in addition. Extensive tundra plains form much of the region; in the north however the terrain is hillier, and in the east, there are low plateaus. There are no large rivers, as the region is split into the many islands of the Canadian Arctic Archipelago. At the present time the population of all these sections is very small, being limited to Eskimos, (Indians in the south), traders, weather observers, and government officials. The mineral wealth of the southern areas appears to be slight. Coal and the possibility of oil have been found by explorers in the western section, but they are so difficult to reach that they must remain undeveloped in the near future.

5. The Western Cordillera. The physiographic division of the Western Cordillera is part of one of the great mountain chains of the world, which extends from southernmost South America to Alaska and by the Aleutian Islands, to northeastern Asia. In Canada the Cordillera may be divided into three major systems, and further subdivided into a large number of smaller sections.

(*a*) *The Eastern Mountain System.* This system is dominated by the Rocky Mountains in which the highest peak is Mt. Robson (12,972 feet). The Rocky Mountains form however only part of the eastern system. On the east side of the system on the border of the Great Plains, mainly in Alberta, is the Foothills Belt, which extends north from the United States border to near the Liard River. The mountains of the Foothills are much lower than the Rockies, have generally smooth slopes, and were not glaciated to the same degree. Rivers have cut deeply into them and the land is rugged.

Immediately to the west and rising up sharply from the Foothills are the Rocky Mountains. North of the Liard River they are continued towards the Arctic Ocean, as the Mackenzie Mountains and the Arctic (Richardson and British) Mountains. The three subdivisions are separated by plateaus through which flow deeply entrenched rivers. The Rocky Mountains are the highest and most jagged of the three ranges. They have a number of peaks over 10,-

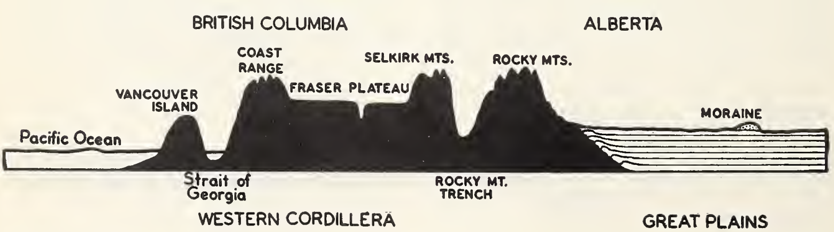


Fig. 16–5. Cross section through southern Canada, approximately from Halifax to Vancouver Island. *Part 3:* from the Great Plains to the Pacific Ocean.

000 feet, and glaciers and small ice fields. The northerly ranges rarely exceed 7000 feet and are ice free. The western boundary of the Eastern Mountain System as far north as the Liard River, is formed by the Rocky Mountain Trench. This great valley is nearly 900 miles long and from 2–10 miles wide. It is occupied in turn by the Kootenay, Columbia, Fraser, Parsnip, Finlay and Kechika rivers.

(*b*) *The Interior Plateaus and Mountain System.* The plateaus and mountains of the interior of British Columbia and Yukon may be divided into three sections and then further subdivided into smaller units. The southern section extends from the United States border as far north as the Skeena River, the central section to near the Yukon border, and the northern section, northwest to the Alaska border. The southern section is composed of three parts. The most spectacular of these are the Columbia Mountains, the name given to a number of high ranges, including the Selkirk Mountains which have peaks over 11,000 feet, and are in many respects similar to the Rocky Mountains. Farther north are the Cariboo and Monashee mountains which are generally lower although still very rugged. The ranges are divided by deep narrow river valleys through which flow many of the large rivers of southern British Columbia. The other two parts of the southern section are the Fraser and Nechako plateaus. These plateaus have a rolling upland surface into which the rivers have cut deep valleys. The Nechako plateau has a level of about 2500 feet and the Fraser plateau of about 6000 feet. When the plateaus are observed from the bottom of the valleys which the highways and railways follow, they look like mountains, and it is only from the top that they look flat. The central section is composed of a complex mass of mountain ranges and plateaus. Some of the peaks in the Omineca and Skeena mountains exceed 8000 feet, and support small glaciers, but the average summit height is much lower, being between 5000 and 6000 feet. In the northern section the Interior System reaches its greatest width and covers over half the Yukon Territory. It is formed principally of two parts, the high and almost unknown mountains of the east which may exceed 9000 feet, and the broad, low Yukon plateau. Running across the plateau in a northwesterly direction is the Tintina Valley, a narrow trench occupied by a number of rivers and in many ways like the Rocky Mountain Trench.

(*c*) *The Western Mountain System.* This system is divided into three parts by the Coastal Trench, which lies between the Coast Mountains of the mainland and the Coastal Ranges of the outer islands. The Coastal Trench is mainly submerged and forms the sheltered Inland Channel used by coastal shipping. Where the Trench is above the sea it forms narrow belts of lowlands and hills. They are found on the east side of Vancouver Island and the mainland, opposite, including the Vancouver area, and on the east side of the Queen Charlotte Islands. The Coast Mountains rise up from the Coastal Trench as a massive granite barrier broken only by the through valleys of Fraser, Stikine and Skeena rivers. The mountain summits exceed 10,000 feet and Mount Waddington reaches 13,260 feet. The precipitation on the west side of the Coast Range is very great because it faces the Pacific Ocean, and in the northwest of the range there are large ice fields. The Coastal ranges include the mountains of Vancouver Island and Queen Char-

lotte Islands. They are lower than other ranges in the Western Cordillera, except in east-central Vancouver Island where the highest peak is over 7000 feet; the majority of summits are nearer 3000 feet. The absence of lowland and the rugged terrain have hindered settlement in the Western Cordillera. Large settlements are restricted to the valleys of southern British Columbia. The wide variety of soils, and climate and rocks typical of all large mountain areas have led to important mining, lumber, and specialized agricultural industries.

6. The Canadian Shield. Although the Canadian Shield is the largest physiographic division in Canada no satisfactory subdivision into smaller sections has been made. This is primarily because the landforms are so similar throughout the region, having developed on the same type of rock (mainly granite). Very broadly the Canadian Shield resembles a basin with a high rim, particularly on the east side from south Ellesmere Island in northern Canada, through the Devon, Bylot and Baffin islands to the Torngat Mountains of northern Labrador. Along this rim, plateaus with summits over 6000 feet are found; in the north there are ice caps, farther south small glaciers. On the south side of the Shield, elevations are lower although they exceed 4000 feet in the Laurentides north of Quebec. The western rim of the Shield has an elevation of about 2000 feet. All but a few of the long rivers flow towards Hudson Bay, which occupies the central part of the basin. Away from the edge of the Shield there are only occasional monadnock mountains, such as the isolated Otish Mountains of central Quebec. The interior of the Shield is formed of two main types of country. The first type is rocky and has low ridges and hills with many lakes, and fast-flowing rivers. Included in this category are the Laurentians and part of northern Ontario. The second type is the plains, which are covered with sands and clays left after the Ice Age; through these deposits project low rock ridges. Such areas are very extensive, and form the Drift Plains of north-central Quebec, the Clay Belt of northwestern Quebec and northeastern Ontario, and the Arctic Plains of Keewatin.

The Canadian Shield is the great source of Canadian metallic mineral wealth. From it are produced great quantities of nickel, gold, uranium, iron, platinum and many other metals. The Shield is in addition the most important source of pulp wood in the country. Because of the harsh climate, poor drainage and thin soils it does not produce good farming areas except in a few special localities.

7. The Innuitian Division. This division is the most northerly and least known of the Canadian physiographic divisions. It forms most of Ellesmere Island and the smaller islands in the northwest of the Queen Elizabeth Islands. The main characteristics are the high mountain ranges reaching nearly 10,000 feet in the United States Range of northern Ellesmere Island; the ice caps and glaciers from flowing down Arctic Ocean in the northwest, and the deeply indented fiord coast line. Although mountains are the main land form of the division there are broad plains and extensive hilly tracts in the southwestern part of the division.

HAVE YOU LEARNED THESE?

This chapter is largely descriptive, and the student is *not* expected to "memorize" it. He may, however, become familiar with the location, rock structure, general topography, and principal industries of each of the important physiographic provinces or sections that have been described.

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1–7. For each major division of Canada, make a chart showing, where it is appropriate: (*a*) subdivisions (provinces or sections); (*b*) location of each subdivision; (*c*) rock structure and bedrock; (*d*) general topography; (*e*) scenic features; (*f*) industries; (*g*) cities.

STUDENT ACTIVITIES

1. Locating and labeling the physiographic provinces and their principal features on a large physical outline map of Canada
2. Studying topographic sheets representing each of the physiographic regions
3. Making relief models of Canada or of parts of Canada
4. Collecting photographs of typical scenery, industries, and natural vegetation in the various physiographic provinces

SUPPLEMENTARY TOPICS

1. The Physiographic Provinces and Their National and Provincial Parks
2. More About the Physiographic Provinces of Canada
3. The Physiographic Provinces of the United States
4. The Physiographic Provinces of Europe

SUGGESTIONS FOR FURTHER READING

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II THE EARTH AND THE UNIVERSE

Look up at the sky on a bright starry night. The heavens appear to form a gigantic dome that hangs over the earth and is lit up in many places by thousands of points of light of varying brightness. Most of these lights sparkle and twinkle as though constantly being turned off and on again, but a very few shine with a steadier light than the rest. The lights are spread unevenly through the sky, and in one large section the whole sky glows white as though sprinkled with "star dust."

Throughout the ages men have gazed at the sky with interest and curiosity. Some of them named the twinkling lights "stars," and the white section the "Milky Way." To some sky watchers, the brighter stars seemed to be arranged in patterns that suggested the figures of men and women and animals. They called these patterns "constellations" and named them after their mythological characters. Watching the skies from hour to hour and from night to night, early astronomers observed that the constellations moved through the sky each night, all in the same direction, in a manner which made it appear as though the dome of the heavens were turning around the earth. And so they thought of the universe as a great hollow sphere with the earth at its center. One half of the sphere had stars set into its darkened surface, while the other half was brilliantly illuminated by the sun. As the sphere turned around the earth, night passed into day and back again.

Then it was noticed that the few "stars" that did not twinkle had a second peculiarity. While all the other stars stayed in precisely the same formations at all times, these few—five in all—shifted their positions as though "wandering" through the other stars. The ancient astronomers called these *planets,* meaning "wanderers," and named them after their gods—Venus, Jupiter, Mars, and others. The wanderings of the planets, as well as the movements of the moon and the sun, were difficult to account for in the "hollow sphere" explanation of the universe, but still this explanation was accepted for thousands of years. In all this time there was no clear idea as to what the stars and planets really were.

In the 16th century the true explanation of the heavenly scene began to develop. The great Polish astronomer Copernicus stated that the turning of the heavens was an illusion caused by the turning of the earth on its axis; that the earth was a planet; and that all the planets revolved around the sun. Copernicus died before his "system" gained general acceptance. In 1609 Galileo invented the telescope, which provided a key to the real nature of the universe. From that day onward, man has obtained more than enough evidence to prove the ideas of Copernicus.

With the aid of giant telescopes and new star-analyzing instruments man has learned that there are many billions of stars in the universe; that these stars are suns, much like our own sun; that the Milky Way is composed of more than a billion stars in a related family called a *galaxy* (*gal* uks ee); that the planets and the sun form a tiny "solar system" which belongs to the Milky Way galaxy; that there are millions of other galaxies; and, finally, that the distances between stars are large almost beyond imagination. The heavens that we look into today are the same as those that the ancients saw many thousands of years ago. The naked eye sees no more in the heavens today than it did then, but the concept of the universe that modern science has provided us is far grander and vaster than that of the past.

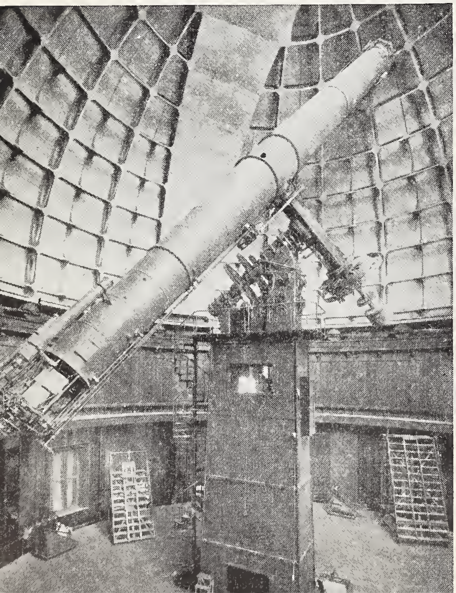
Chapter 17

STARS AND GALAXIES

1. Stars and suns. The astronomer of ancient times knew nothing of the real nature of the stars. To him they were simply mysterious ornaments in the sky dome. The astronomer of today knows that the stars are brilliant fiery suns similar to our own sun but very much farther away. If our sun were far enough from us, it would look like a star. On the other hand, if any of the stars were close enough to us, they would look like suns.

Fig. 17–1. The great 36-inch refracting telescope of the University of California's Lick Observatory at Mount Hamilton, California.

Lick Observatory Photograph



2. Seeing stars. The darker the surroundings the easier it is to see the stars. The starry sky looks brightest on a night when there is no moon and from a position where no street lights or other artificial light can blur the light of the stars. Stars are in the sky by day as well as by night, but the brilliant light of the sun completely outshines their far fainter light, making the stars quite invisible.

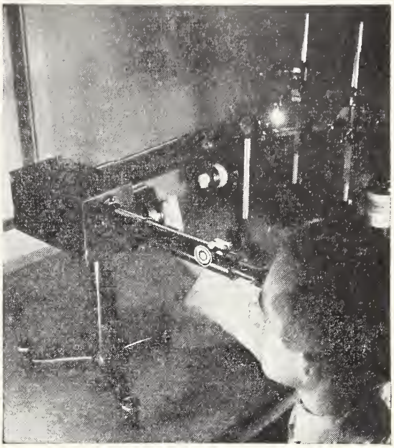
3. How many stars? While the brilliance of the sky on a clear moonless night seems to show an infinite number of stars, a careful star-by-star count reveals about 5000 stars actually visible to the naked eye in the heavens of both the Northern and Southern Hemispheres. Only about 2000 of these stars can be seen by an observer at any one time. But with the aid of the wonderful telescopes of modern times, millions of stars can be seen, while more millions of still fainter stars can be shown by photographic plates that are much more sensitive than the human eye.

4. The telescope. The telescope is an instrument whose lens or mirror, much larger than the lens of the human eye,

can gather together a much greater quantity of light from a star and focus it in one spot. If the eye is placed near that spot, it sees hundreds or thousands of times as much light from the star as it can see "naked" or without the telescope. Stars already visible look much brighter—not larger—and millions of stars that are invisible to the naked eye become visible through the telescope. Sensitive photographic plates, placed at the focus of the telescope's light and exposed for many hours, show large numbers of stars that the eye, even through the telescope, is unable to perceive.

A telescope that uses *lenses* to focus starlight is called a *refracting telescope* or a *refractor*. The world's largest refractors are those of the Yerkes Observatory at William Bay in Wisconsin, and the Lick Observatory at Mount Hamilton in California. The Yerkes lens is 40 inches in diameter; the Lick lens is 36 inches in diameter. A telescope that uses a curved *mirror* to focus the starlight is called a *reflecting telescope* or *reflector*. The world's largest reflectors are the telescopes at Mount Palomar and Mount Wilson, both in California. The Palomar mirror is 200 inches, or almost 17 feet, in diameter! The Mount Wilson mirror is 100 inches in diameter.

5. What stars are made of. The chemical composition of a star can be determined by the *spectroscope* (*spek* truh skohp). Stars, like the sun, are made of chemical elements so hot that all of them are in the form of glowing gas or vapor. The spectroscope is an instrument which analyzes the light given off by incandescent (glowing-hot) materials so that the scientist can tell which elements they contain. Thus far 66 of the 92 natural earth elements have been identified in our sun, and the other



Courtesy Bausch & Lomb Optical Co.

Fig. 17–2. Using the spectroscope to analyze the light from an incandescent solid.

stars appear to be made of the same elements.

6. How large is a star? There is a tremendous range in the sizes of stars. The smallest stars, known as *dwarfs*, have diameters of about 10,000 miles, making them only a little larger than the earth. The largest stars, known as *giants*, have diameters up to 2,000,000,000 (2 billion) miles! Our sun, an average-sized star, has a diameter of 864,000 miles, a distance almost equal to four trips from the earth to the moon. Antares (an *tar* eez) and Betelgeuse (*beet*'l jooz), two of the bright stars of our sky, are classed among the giants, with diameters hundreds of times as large as the sun's.

7. How far to a star? Distances between the stars are so great that a special unit, the *light-year*, is used to describe them. A *light-year is the distance a ray of light can travel in one year.* Light travels at a speed of 186,000 miles per second. Let us see how many miles there are in a light-year.

1 light-year = 186,000 miles × 60 (seconds) × 60 (minutes) × 24 (hours) × 365 (days). Working this out, we find that a light-year is about 6,000,000,000,000 (6 trillion) miles. Next to our sun, the star nearest to the earth is a star called Proxima Centauri (*proks* ih mih *sen* tawr ee). It is about 270,000 times as far away as the sun! While light from the sun takes only 8 minutes to travel the 93,000,000 miles to the earth, light from Proxima Centauri takes 4 1/3 years to reach us, so we say it is 4 1/3 light-years away. Proxima Centauri is a Southern Hemisphere star. Sirius, the brightest star in the Northern Hemisphere sky, is 8 light-years away, while giant Arcturus is 38 light-years away. The most distant object visible to the naked eye is about 800,000 light-years from the earth! Our most powerful telescopes can see to a distance of more than 1,000,000,000 (one billion) light-years.

8. Star colors and their meanings. To the casual observer all stars look much alike. A careful second glance, however, will show that stars differ in color, even to the naked eye. Some stars are reddish, some yellowish, some white or bluish-white. Studies of star colors show that the colors indicate how hot the stars are. A metal bar heated blazing hot turns first red, then orange, then yellow, and finally white. The same thing is true of the stars. The gases of the stars are glowing hot. The red stars are the coolest, the yellow stars are hotter, and the white or blue-white stars are the hottest stars. At the surface of a star, where it is coldest, a red star like Betelgeuse or Antares may have a temperature of 4000° F. Our sun, a yellow star, has a surface temperature of about 10,000° F, while Rigel (*rye* jel), a blue-white star, may have a surface temperature of 100,000° F. In their interiors the stars are much hotter, their temperatures running into the millions of degrees.

Like a red-hot bar of iron or the white-hot tungsten filament of an electric-light bulb, the gases of stars glow and give off energy even though *they are not burning.* Scientists are not certain where the energy comes from, but one theory is that it comes from the splitting of the nuclei of atoms, as in the atomic bomb. Another theory is that the energy comes from the union of hydrogen atoms to form helium, as in the H-bomb that scientists are now trying to create.

9. Star brightness. The flame of a match held a few inches from the eye is more dazzling than a 300-watt bulb in the ceiling of an auditorium. So it is with the "lights" in the heavens. The brightest stars are not necessarily bigger and brighter than the other stars. The brightness of a star, as we see it, depends upon its temperature, its size, and its distance from the earth. Stars that appear very faint may actually be as bright as the brightest we see; they may look fainter simply because they are much farther away.

When astronomers classify the stars according to their apparent brightness, they use the word *magnitude. First-magnitude stars* are the brightest stars. There are about twenty of these in the sky, including such now-familiar names as Betelgeuse, Antares, Arcturus, and Rigel. *Second-magnitude stars* are 2.5 times less bright than "firsts," and so on. Polaris (poh *lay* riss), the North Star, is a second-magnitude star. The dimmest stars visible to the naked eye are sixth-magnitude stars, which are just about 1/100th as bright as "firsts." The great 200-inch reflector telescope at Mount Palomar can detect, by photo-

graph, stars of the twenty-third magnitude, about 1/500,000,000th as bright as first magnitude stars!

The brightest star of all, Sirius (*sir* ee us), is far brighter than the average first-magnitude star. But two of the planets —the "steady lights of the sky"—are even brighter. The two are Venus and Jupiter.

10. Galaxies: stars that belong together. Even before Galileo's invention of the telescope, sky watchers noticed that in addition to the several thousand sharp points of light they called stars there were a few hazy, blurred patches in the nighttime sky to which they gave the name of *nebulae* (clouds). Early telescopes revealed thousands more of these, and modern telescopes

Fig. 17–3. Diagram showing how galaxies are distributed in space.

have shown that many of these nebulae are really systems or families containing millions of stars. Today we call these systems *galaxies*. Although galaxies are millions of light-years apart, our giant telescopes indicate that space contains at least 100,000,000 galaxies, each probably including many millions of stars! The great 18th century astronomer Sir William Herschel called these galaxies "island universes" to emphasize the vast emptiness of space between them.

The galaxy to which the earth belongs is called the *Milky Way*. In this galaxy our sun is one star among many billions of stars, and its nearest neighbor is Proxima Centauri. *Every star that we*

Mount Wilson and Palomar Observatories

Fig. 17–4. Galaxies in the constellation Pegasus, photographed with the 200-inch telescope.

can see with the naked eye is part of our Milky Way. Astronomers think that our galaxy is shaped like a disk or a thin watch; that its diameter is about 100,000 light-years and its greatest thickness about 10,000 light-years; and that the sun is about two-thirds of the way from the galaxy's center to its edge. When we look along the plane of the "watch," we see so many stars that the sky appears

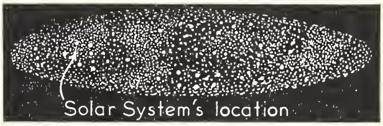


Fig. 17–5. Diagram of the Milky Way Galaxy.

"milky." When we look through the thickness of the watch, we see fewer stars in that part of the sky. The entire galaxy rotates in one direction, but its stars may move at different speeds and in different directions.

The nearest galaxy outside the Milky Way is the one faintly visible to the naked eye as the famous Great Spiral in the constellation Andromeda. This galaxy is estimated to be about 800,000 light-years away. Next to our own Milky Way, it seems to be the largest galaxy

Lick Observatory Photograph

Fig. 17–6. The Great Spiral Nebula in Andromeda is the nearest, brightest, and largest of all galaxies except our own Milky Way. At a great distance, the Milky Way would look like this.

yet discovered. It is the only other galaxy the naked eye can see.

11. Constellations: star patterns. The stars that the ancients saw close together in the sky are in most cases not near each other at all. They are located in the same direction in space, but may in reality be vast distances apart, just as an airplane and a bird may appear to be near each other though actually far apart. To these groups, or "constellations" of stars, the Greeks, Romans, Egyptians, Chinese, Arabs, American Indians, and in fact star watchers all over the world, gave names often taken from their mythologies. Most of the names in use today are of Greek or Latin origin.

The best-known of the constellations is probably Ursa Major, the Great Bear, in which the Big Dipper forms the tail and part of the back. A line through the "pointer" stars in the bowl of the Big Dipper points to Polaris, the North Star. When you look at Polaris you are looking north. Other famous constellations are Ursa Minor, the Little Bear, containing Polaris; Orion, the Mighty Hunter, containing Betelgeuse and Rigel; Taurus the Bull, with the Pleiades, or Seven Sisters.

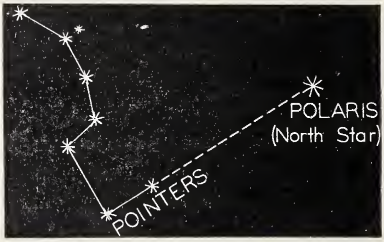


Fig. 17–7. Using the Big Dipper to find Polaris.

Since all the stars are moving at high speeds and usually in quite different directions, why do the constellations always make the same patterns? The answer is that at the stars' great distances, it will take many thousands of years before their motions carry them far enough apart to make much visible difference to us. But eventually the constellations will change, and the Big Dipper of 100,000 years from today will no longer justify the name of dipper.

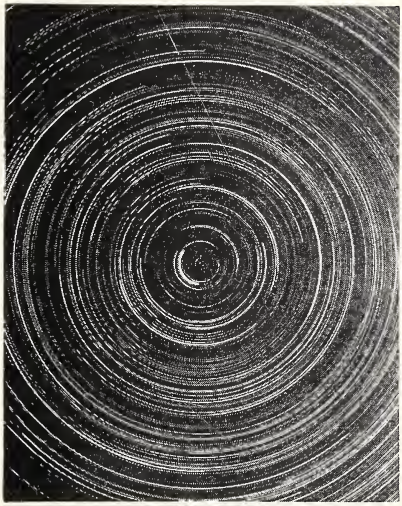
Fig. 17–8. Why the nighttime sky is different in summer and winter.

12. Summer skies and winter skies. The summer sky and the winter sky show us different constellations. The stars we see at any time are those on the nighttime side of the earth facing away from the sun. In summer and winter the earth is at opposite ends of its orbit, or path around the sun. Since the nighttime sky is on the side away from the sun, it is a different part of the sky in summer than in winter and has different stars in it. (See Figure 17–8.)

13. The turning of the heavens. Today, just as 2000 years ago, the whole sky dome appears to turn from east to west during the night. *This appearance of turning is a result of the turning of the earth from west to east on its axis.* Since the axis is pointed almost exactly at Polaris, the North Star, this star seems to remain almost stationary in the sky, while the stars near it appear to go around it in circles from east to west and can be seen all night. The farther the stars are from Polaris the larger their circles become, until the more distant stars simply appear to rise in the east and set in the west, and may be seen for only a part of the night. The tracks made by the stars as they pass through the sky each night can be photographed with an ordinary camera by time exposure. The circumpolar stars (those around Polaris) make circular "trails," while those far from Polaris produce straight trails.

Lick Observatory Photograph

Fig. 17–10. Star trails made by stars far from Polaris in the sky. The building in the photograph is the Lick Observatory.



Lick Observatory Photograph

Fig. 17–9. Circumpolar star trails. These circular trails are the all-night photographs of the North Star and the stars near it. The bright trail almost at the center is the North Star's.

HAVE YOU LEARNED THESE?

Meanings of: spectroscope, light-year, galaxy, constellation

Explanations of: what the telescope and spectroscope do; refracting and reflecting telescopes; the material, size, and distances of the stars; the brightness of a star

Relations between: suns and stars; stars and galaxies; stars and constellations; constellations and seasons; star color and temperature; the sun and the Milky Way; Ursa Major, the Big Dipper, and Polaris, the North Star

Expression of: star brightness in terms of magnitudes

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. How do the sun and stars resemble each other? Why do they look different?

2. Why cannot stars be seen in the daytime sky?

3. Compare the number of stars visible to the naked eye with the number seen through the telescope.

4. (*a*) How does the telescope make faint stars visible? (*b*) How does a refracting telescope differ from a reflecting telescope? (*c*) How large are the world's largest telescopes? Where are they?

5. How does the spectroscope tell what stars are made of? What are they made of?

6. How does the sun compare in size with other stars? Name two giant stars.

7. (*a*) Define light-year. Why is this unit used? (*b*) Next to the sun, which is the nearest star? (*c*) How far into space can we see?

8. (*a*) How are the color and the temperature of a star related? Why? (*b*) Give examples of stars of different colors. What are their temperatures? (*c*) Are stars "burning up"? Where does their energy come from?

9. (*a*) What determines how bright a star looks to us? (*b*) How does the astronomer describe star brightness as we see it? Explain. (*c*) What star magnitudes can be seen with the naked eye? with the telescope? How do these stars compare in brightness with first-magnitude stars? (*d*) Compare the brightness of Betelgeuse, Sirius, and Venus.

10. (*a*) What is a galaxy? How many galaxies are there? How far apart are they? (*b*) Name and describe our galaxy. (*c*) Name and describe the galaxy nearest to ours.

11. (*a*) What are constellations? How did they receive their names? (*b*) Why is the Big Dipper so well known? (*c*) Will the constellations ever change?

12. Why do we see different constellations in summer and winter?

13. (*a*) How do you explain the apparent turning of the heavens? (*b*) What are star trails? Compare the trails made by: (1) Polaris; (2) stars near Polaris in the sky; (3) stars far from Polaris in the sky.

GENERAL QUESTIONS

1. Why is it possible to photograph stars that are invisible to the eye?

2. If the diameter of Betelgeuse is 200 times as great as the sun's diameter, how does the volume of Betelgeuse compare with the volume of the sun?

3. The moon is 240,000 miles from the earth. How long does it take moonlight to reach us?

4. Why should the interior of a star be hotter than its surface?

5. How can planets be brighter than stars?

6. (*a*) Can a constellation contain a galaxy? Explain. (*b*) Can a galaxy contain a constellation? Explain.

7. If an observer stays up late on an autumn night, he sees winter constellations. Why?

8. Star trails in the United States can never be complete circles. Why?

9. Where would one have to go in order to photograph star trails that were complete circles? Why?

10. Calculate the number of miles in a light-year. How many miles away is Proxima Centauri?

11. Why is the Mount Palomar telescope four times as powerful a light-gatherer as the Mount Wilson telescope?

STUDENT ACTIVITIES

1. Photographing stars and star trails
2. Learning to identify the constellations outdoors
3. Learning to identify the first-magnitude stars
4. Charting the Big Dipper (and other

constellations) at the same hour each night and at different hours in one night

5. Charting the "wanderings" of a planet

6. Stargazing through a telescope or binoculars

7. Using a spectroscope
Making a telescope
Making a "star-box"

SUPPLEMENTARY TOPICS

1. The Astronomer's Telescope
2. The Story of the Telescope
3. The World's Great Telescopes
4. Star Photography
5. The Spectroscope and Its Uses
6. Super-giant, Giant, and Dwarf Stars
7. Other Units of Distance in Astronomy
8. Measuring Star Temperatures
9. Measuring Star Distances
10. Other Galaxies
11. Types of Nebulae
12. Star Clusters
13. Origin of the Solar System
14. The Stories of the Constellations
15. First-Magnitude Stars

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Chapter 18

THE SUN AND ITS FAMILY

1. The solar system. Deep in the interior of the Milky Way, in the distant company of millions and millions of other star members of the same great community of stars, our sun whirls its way through space. But the sun has a family, and wherever it goes its family goes with it. This family, known as the *solar system,* includes a multitude of objects ranging in size from tiny sandlike grains to gigantic balls of rock tens of thousands of miles in diameter. In the sun's family there are nine planets, thirty satellite moons, thousands of planetoids, millions of meteors, and numerous comets. These bodies travel around the sun at high speeds. *Centrifugal* (sen *trif* yuh g'l) *force* tends to make them fly away from the sun and off into space, while the *gravitational force* of the sun tends to draw them into its center. These forces generally balance, and the objects keep traveling around the sun in paths called *orbits,* at distances ranging from millions to billions of miles.

2. Seeing the family. How do we recognize members of our solar family? The sun, star of the family, is familiar to everyone and is unmistakable. So is our moon. Meteors are familiar to us as "shooting stars." Comets are seen rarely by most of us, but almost all of us have seen pictures that would help us identify a comet if we saw one. Five planets can easily be seen with the naked eye, but the planetoids and the most distant planets can be seen only through telescopes.

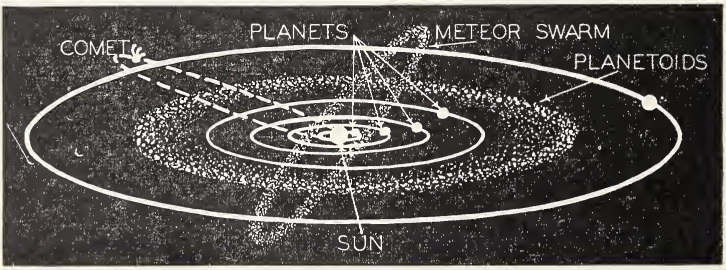

Fig. 18–1. The solar system as far as Jupiter. The planetary orbits shown are those of Mercury, Venus, Earth, Mars, and Jupiter. To show the outermost orbit, that of Pluto, the diagram would have to be about four times as long as it is.

To the naked eye planets look very much like stars, but several visible differences enable us to tell them apart. First, since planets are so very much closer to the earth than the stars are, their motion around the sun is plainly noticeable as a daily shifting of their positions in the sky. As the ancient astronomers observed, the planets "wander" among the constellations, while true stars always keep the same formations. Again, because stars are so very far away, the telescope can only make them look brighter but not larger. Most planets, on the other hand, are near enough to the earth to be magnified by the telescope into flat bright circles rather than mere bright pinpoints of light. On these flat circles, which the astronomer calls *visible disks*, details of the planets' surfaces can be seen. A third difference between stars and planets is that stars always twinkle, while planets shine steadily except when they are close to the horizon.

Twinkling can be described as the appearance of going on and off, or changing from bright to dim and back again. There are several reasons for twinkling, one being the fact that air currents bend and interrupt the single ray of light from the distant star. Planets twinkle less because their large disks send out enough rays of light so that not all of them are cut off at one time.

The hot gaseous stars shine by their own light and are said to be *self-luminous*. Planets, on the other hand, shine by reflecting the light of the sun, and are said to be *illuminated* or *nonluminous*.

3. Planets of rock; size. The nine planets are the most important members of the sun's family. They appear to be "chips of the old block," as do all the members of the family, being composed of the same elements as the sun. But while the sun is hot and gaseous, the planets are composed of solid rock surrounded by water and atmosphere, for apparently these smaller pieces of the sun cooled off long ages ago. On Mercury, Venus, Earth, and Mars, the four planets nearest the sun, the water is mostly in liquid form, except for icecaps at the polar regions of Earth and Mars. But Jupiter, Saturn, Uranus, and Neptune are so far from the sun and so cold that all their water seems to be frozen solid on top of their rock cores. On Pluto, the most distant planet, even the atmosphere is probably frozen.

Compared with the sun's 864,000 mile diameter, giant Jupiter, largest of the planets, is tiny. Its diameter of over 88,000 miles is about one-tenth that of the sun. Nearly a thousand Jupiters could fit into the sun. Saturn is slightly smaller than Jupiter. Neptune and Uranus, which are nearly alike in size, have less than half the diameter of Saturn. These planets are the "big four." The others are much smaller, ranging in size from Earth down through Venus, Mars,

Jupiter	Saturn	Uranus	Neptune	Earth	Venus	Mars	Pluto	Mercury
88,640	74,100	32,000	31,000	7927	7700	4215	3550	3100

Fig. 18–2. Equatorial diameters of the planets in miles. The sketches of the planets are drawn to scale and show their relative sizes.

and Mercury; Pluto's size is uncertain. Venus and Earth are so nearly the same size that they are often called twin planets. Mars is about half the diameter of Earth, and Mercury is still smaller.

4. Distance, orbit, and year. Mercury, the planet nearest the sun, is at an average distance of 36,000,000 miles. Pluto, farthest from the sun, is at an average distance of 3,670,000,000 miles —just about one hundred times as far as Mercury. Between Mercury and Pluto come Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Mercury, Venus, Mars, Jupiter, and Saturn are large enough and close enough to Earth to be visible to the naked eye. Although Uranus can be seen without a telescope, it is very faint, and so was not known until 1781, when it was "discovered" by Sir William Herschel, the great English telescope maker and astronomer. Neptune and Pluto, visible only with the telescope, were discovered in 1846 and 1930 respectively. Pluto is so far away from the sun that the sun looks no larger in its sky than a star does to us. On Mercury, by contrast, the sun would nearly fill the sky.

All the planets travel from west to east around the sun in elliptical (oval) paths called orbits. All of the orbits except Pluto's are almost circular, so that there is not very much difference between the smallest and the greatest distance from each planet to the sun. But Pluto's orbit is very *eccentric* (off center). When Pluto is at the far end of its orbit, it is almost twice as far away as when it is nearest the sun.

The time it takes a planet to travel (revolve) around the sun is called a year. This time depends upon the size of the planet's orbit and the speed at which it travels. It so happens that the closer a planet is to the sun, the faster it travels. As a result, the nearer the planet is, the shorter its year is. Mercury's year, shortest of all, is only 88 of our days. Mars, farther from the sun than the earth is, has a year almost twice as long as ours, while Pluto, out at the very outskirts of the solar system, takes 248 Earth years to revolve around the sun!

5. A day on a planet. The time it takes a planet to turn once (rotate or spin) on its axis is its *day*. The *axis* is the imaginary line, stretching from North Pole to South Pole, around which the planet spins. Surprisingly, we find that Jupiter, the largest planet, spins around in less than 10 hours, faster than any other planet. Saturn, the second largest planet, is also the second-fastest spinner, completing its day in about 10¼ hours. Earth and Mars have almost identical days of about 24 hours and 24½ hours respectively. Venus, its surface difficult to observe through its densely clouded atmosphere, seems to take about 30 days for its rotation. Mercury takes 88 days, and Pluto's spinning time is unknown. Uranus and Neptune rotate in about 11 and 16 hours respectively.

A spinning sphere such as a planet develops tremendous centrifugal force around its middle, or *equator*, where it tends to bulge while becoming flattened at its poles. The amount of the bulge depends upon the size of the planet, the speed at which it spins, and the state of the material of which it is composed. Jupiter, the largest and fastest-spinning planet, is affected most in this way, while Saturn, second in size and spinning speed, is affected almost as much. Our own Earth is 27 miles wider through its equator than through its poles. A sphere flattened in this way is called an *oblate spheroid*.

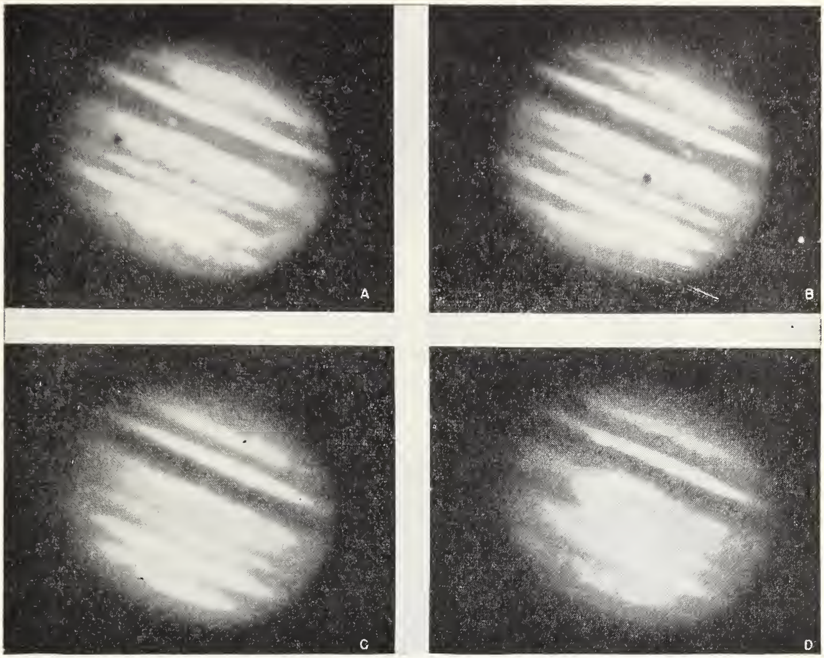

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Fig. 18–3. Four photos of Jupiter showing its *oblate spheroid* shape and its belts. The black spot on Jupiter in *A* is the shadow of one of its moons. In *B*, taken 50 minutes later, the moon casting the shadow is seen as the white spot just above the letter *B*. Photos taken by the 200-inch reflector.

6. Between Mars and Jupiter: planetoids. The planetoids were unknown until 1801. For a long time astronomers had felt that there was a "missing planet" in the too-large space between Mars and Jupiter (see Figure 18–1). In 1801 the Italian astronomer Piazzi discovered the "planet" Ceres, which has since turned out to be simply the largest of the planetoids. More than a thousand of these planetoids, or balls of rock, ranging in diameters from about 500 miles to less than 1 mile, *revolve around the sun in the space between Mars and Jupiter*, each in its own orbit. They are too small and too far from the earth to be seen with the naked eye. Through telescopes they look like faint stars and are therefore often called *asteroids* (like stars) as well as planetoids (like planets). Like the planets, they shine by reflecting sunlight and are recognized by the fact that they "wander" very rapidly through the stars. While most of the planetoids are between Mars and Jupiter, a few of them have been discovered nearer to the earth than Mars or farther away than Jupiter.

Where did the planetoids come from? One theory is that there was once a single planet in the part of the solar system now occupied by the planetoids. Coming too close to Jupiter, this planet was torn to pieces by Jupiter's powerful

gravitational attraction. The pieces continued to revolve around the sun, each in its own orbit, forming the planetoids we see today.

7. Around the planets: satellites. As the earth revolves in its orbit around the sun, the moon revolves around the earth. We call the moon a *satellite* (*sat* uh lyte). A *satellite* is a small body revolving around a larger body. Except for Mercury, Venus, and probably Pluto, each of the planets has at least one satellite.

Mars has two tiny moons, each less than 15 miles in diameter. Phobos, the nearer one, is less than 4000 miles from the surface of Mars, around which it races in 8 hours—three times each day! Our moon is over 2000 miles in diameter, is 240,000 miles from the earth, and takes 27 1/3 days to revolve around it.

Jupiter has eleven moons. Two of them are about the size of our moon, and two are even larger, being about the size of the planet Mercury. While most of the satellites in the solar system revolve from west to east, as do all the planets, Jupiter's three most distant moons revolve "the wrong way" from east to west. Saturn has nine moons, Uranus five and Neptune two. Saturn is also surrounded by three rings, one inside the other, passing around its equator. Once thought to be solid, these rings are now known to consist of millions of bits of rock and dust, all revolving around Saturn. Like all the moons, the rings shine by reflecting sunlight.

Fig. 18–4. Saturn and its rings. Photo taken by the 100-inch reflector.

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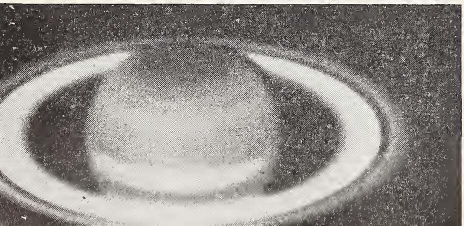

Some of the moons mentioned in the preceding paragraph were discovered very recently through patient and systematic use of the great new telescopes; more moons may be revealed in the years to come. Jupiter's tenth and eleventh moons were discovered in 1938, Uranus' fifth moon in 1948, and Neptune's second in 1949. Even as this is being written, Dr. Nicholson of the Mount Palomar Observatory believes he has discovered a twelfth moon of Jupiter.

8. The comets. To the ancients perhaps the most mysterious and dreaded of all the heavenly bodies were the comets. Even today many people speak of comets with awe and fear, although most people have never seen a comet. As with the stars and the planets, there are large comets and small ones, bright comets and dim ones, distant comets and near ones. Most comets can be seen only through telescopes. A comet visible to the naked eye is a rather rare sight; a truly spectacular comet is even rarer.

The most famous of the comets is Halley's comet. It was named after the Astronomer Royal of England, Edmund Halley. Halley was the first astronomer to recognize that comets are members of the solar system that revolve in orbits around the sun and return to view at regular intervals. The orbits of the comets are very large and very *eccentric*; that is, they are off center, coming much closer to the sun at one end than at the other. When comets come near the sun they are near us and we can see them. Then they go off into the far reaches of the solar system and are out of sight for many years, the number of years depending on the sizes of their orbits. Encke's comet, which has the smallest orbit, visits us every 3.3 years, while Halley's comet reappears about every 76 years.

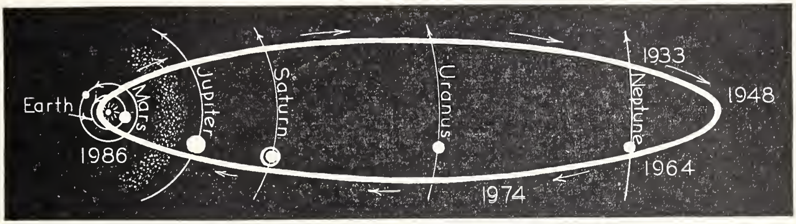

Fig. 18–5. The orbit of Halley's comet extends from a position near the earth to far beyond the orbit of Neptune. Comets have very eccentric orbits.

A comet is shaped like a long narrow torpedo, sometimes stretching out as long in the sky as the Big Dipper. The narrow *head* of the comet, apparently composed of billions of small bits of rock and dust, shines brightly by the reflection of sunlight. As the comet approaches the sun, gases seem to be exploded out of its head to form a *gigantic tail that points away from the sun* and extends millions of miles into space. The tail glows too, though not as

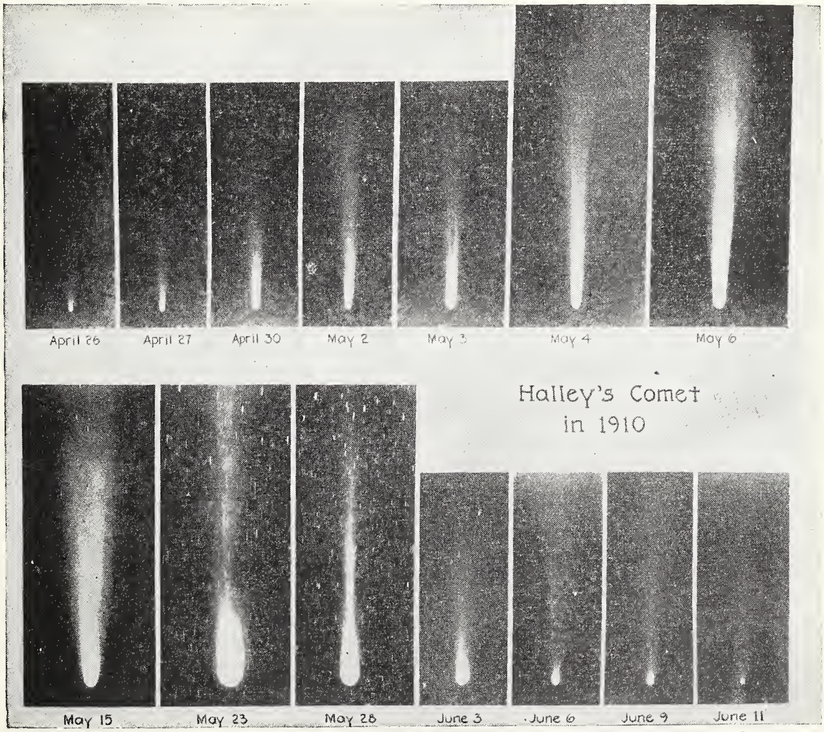

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Fig. 18–6. Fourteen successive views of Halley's comet from April 26 to June 11, 1910, during its most recent visit to the earth. Notice how the tail changes in length.

brightly as the head, and its glow seems to be caused chiefly by light given off by the gas itself, like that from the gas in a neon tube. The tail points away from the sun because the pressure of the sun's rays actually repels the gases! While comets travel at very high speeds, they are so far off that they may stay visible in the sky for weeks or even months. Contrary to the impression given by photographs, comets do not "streak" across the sky like rockets.

In 1910, when Halley's comet made its most recent appearance, the earth passed right through its tail. The prediction of this event aroused great excitement. Many people expected the end of the world. But the gas of the tail was so thin that no traces of it were found in our atmosphere even after careful chemical analysis. Halley's comet will return to our sky in 1986. (See Figure 18–5.)

9. The meteors. Most of us have seen meteors. We usually call them "shooting stars." *Meteors* are pieces of stony or metallic rock, most of them as small as sand grains, though some are as large as gigantic boulders. Billions and billions of meteors are widely scattered throughout the space of the solar system, some traveling alone and others revolving around the sun in great *meteor swarms* that include billions of particles. Meteors travel at speeds of many miles a second, and when they approach close enough to the earth, they are pulled

Fig. 18–7. Ahnighito, the great nickel-iron meteorite found at Cape York, Greenland by Admiral Peary in 1895. It is 11 feet long, 5 feet wide, 7 feet high, and weighs 36½ tons.

Courtesy American Museum of Natural History

toward the earth by gravitation. Their brilliant streaks of light, rarely lasting more than a second, usually develop only after they come within about 60 miles of the earth's surface, and are the result of the intense heat produced by friction with the atmosphere. Meteors whose light is unusually large and bright are called *fireballs.*

Small meteors burn up completely in the upper air; larger ones may land on the earth, where they are called *meteorites.* It is estimated that millions of meteors enter the earth's atmosphere every hour, but very few reach the surface. The Field Museum in Chicago and the Hayden Planetarium in New York City have excellent collections of meteorites which show plainly how these "visitors from outer space" differ from the earth's own rocks. The largest meteorites weigh many tons.

At a few places on the earth giant meteorites appear to have crashed into the ground with enough force to explode deep *craters.* The world's largest known crater of this type is Meteor Crater in Arizona. It is almost a mile in diameter and about 600 feet deep. A large, lake-filled crater has been discovered in the barren grounds of northern Quebec, but its meteoric origin has yet to be proved.

Meteor showers occur when the earth crosses the orbit of a meteor swarm. Large numbers of meteors are seen on such nights, the "showers" usually being named after the constellation in the sky from whose direction they seem to come. Three of the best-known meteor showers are the Perseids (*per* seh ids), which occur every year about August 12; the Orionids (oh *ry* un ids), which occur about October 20; the Geminids (jem uh nids), about December 10. Some of the meteor swarms are believed to have formed when comets that passed near the earth broke up or lost some of the material from their heads (Figure 18–1).

United States Army Air Force

Fig. 18–8. Air view of Meteor Crater, Arizona.

A recent development in the study of meteors is the use of radar to detect their flight into the earth's atmosphere. Since meteors no longer need be seen to be "observed," they can now be studied in the daytime as well as by night.

10. The sun. The sun has already been described as a more or less average star. It is a sphere of hot glowing gases 864,000 miles in diameter and generally yellow in color. This visible yellow face of the sun is called its *photosphere,* meaning "light sphere." Above the photosphere is the sun's atmosphere, including the *chromosphere* and the *corona.* The *chromosphere,* or "color sphere," is a layer of gas thousands of miles high, colored red by glowing hydrogen. From time to time great red streamers, hundreds of thousands of miles high, erupt from the chromosphere. These *prominences* can be seen during a total solar eclipse. The *corona,* or "crown," is the outer layer of the sun's atmosphere, consisting of very thin gases reaching hundreds of thousands of miles above the sun's surface. Ordinarily invisible against the dazzling brilliance of the photosphere, the corona can be seen when the sun is totally eclipsed. It appears as a beautiful halo, yellow below and pearly white above, from which long

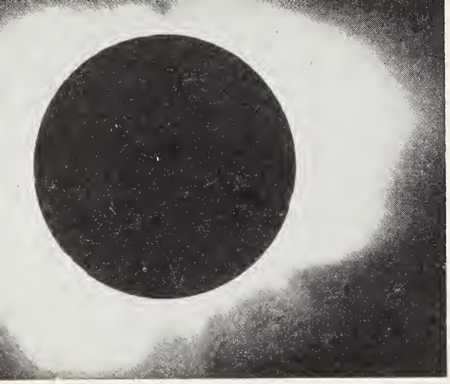

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Fig. 18–9. The sun's corona photographed at Green River, Wyoming during the total solar eclipse of June 8, 1918.

streamers may extend a million miles into space.

The sun's photosphere is not of uniform brightness. Here and there dark patches, called *sunspots*, are seen. They appear to be storm areas in the atmosphere of the sun. Large sunspots may be as much as 90,000 miles in diameter and may be visible to the naked eye protected by a very dark filter. Sunspots are not quite as hot or as bright as the photosphere behind them, so they look dark by comparison. Like storms on the earth, sunspots form gradually, grow larger, and then gradually disappear. They may last for weeks or even months. The number of spots on the sun is continually changing; it reaches a maximum approximately every 11 years. The reasons for this "cycle" are not known.

The appearance of large numbers of sunspots results in *magnetic storms* on the earth. At such times we have great difficulty with telephone, telegraph, radio, and television reception, while unusually beautiful auroral displays of Northern and Southern Lights may occur.

The sun rotates on its axis from west to east, carrying the sunspots around with it. It moves faster at its equator than at its poles. At the equator, rota-

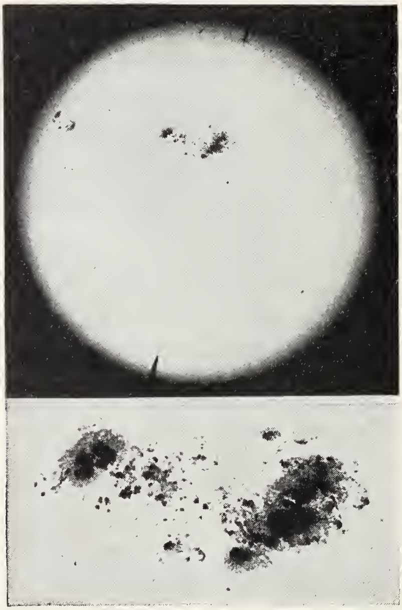

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Fig. 18–10. The whole face of the sun—the photosphere—showing sunspots. The lower picture shows the central sunspot greatly enlarged.

tion takes about 25 days; near the poles it takes about 33 days.

11. Morning and evening stars. As the sun sets in the late afternoon and the sky begins to darken, the stars become visible. The first "star" to be seen in the deepening twilight is often called the "evening star." Similarly, the last "star" still visible before sunrise is called the "morning star." Very often this brightest of "stars" is the planet Venus, since Venus is by far the brightest of the planets and is brighter than any star. Venus, nearer to the sun than the earth is, can never be seen on the nighttime side of the earth. As an evening star, it shines brilliantly in the western sky for a short time after sunset, before it sets in the west as the sun did. As a morn-

ing star, it is seen in the eastern sky shortly before sunrise. When daylight advances, Venus remains in the sky but it becomes less and less visible because of the blinding light of the sun.

Mercury also lies closer to the sun than the earth does, and so, like Venus, it is never visible at night; it is seen only as a morning or an evening star. Mercury is smaller than Venus and not as bright; it moves much more rapidly in its smaller orbit and is much nearer the sun. As a result, Mercury is very difficult to see. Venus, on the other hand, is visible most of the year as either a morning or an evening star.

When Mars, Jupiter, and Saturn are close to the sun at sunrise or sunset, they may also be called morning and evening stars. Since these planets have orbits beyond the earth's, they appear in our nighttime sky during a large part of the year.

12. Recognizing the planets. The planets are easily identified. Venus is the brightest "star" in the heavens. It is seen only in the western sky in the evening or in the eastern sky in the early morning. Through a telescope it shows phases like those of the moon, a result of its position between us and the sun. It is brightest at its crescent phase, since it is then nearest to the earth.

Mercury, like Venus, can be seen only as a morning or an evening star, very close to the sun, and about as bright as a first-magnitude star. Venus has a silvery glow; Mercury is somewhat reddish in color.

Jupiter is next in brightness to Venus; it can be seen in the nighttime sky long after Venus may have set. Its steady light is silvery in color. Through the telescope Jupiter shows a series of bands or belts parallel to its equator. These bands are believed to be caused by great clouds in its atmospheric currents. The telescope also easily reveals the four largest of Jupiter's moons (Figure 18–3).

When Mars is close to the earth, it may be brighter than Jupiter. Ordinarily it is of about first-magnitude brightness and is distinctly red in color. The telescope shows many details of Mars' surface, such as the lines called "canals" and the polar icecaps (Figure 18–11).

Saturn, almost as large as Jupiter but much farther from both the sun and the earth, shines about as bright as a first-magnitude star and is yellow in color. A telescope shows its remarkable rings, which make it absolutely unmistakable.

13. Life on Mars? Whenever the possibility of life on other planets is considered, the discussion centers on Mars. Conditions on Mars seem most favorable for supporting life. Its appearance through the telescope suggests the existence of life. The many narrow canal-like lines seen on its surface could be the work of living beings. The length of a day on Mars is almost exactly the same as on the earth, and the year and the seasons are only about twice as long as ours. The green color of its springtime and the browner color of its fall season seem to correspond to the seasonal blooming and withering of vegetation on the earth. The white polar caps grow larger in winter and smaller in summer just as our own great polar glaciers must behave. Finally, Mars has an atmosphere. Mars' atmosphere is thinner than the earth's and seems to contain very little oxygen or water vapor.

The existence of life on Mars has been neither proved nor disproved, but astronomers today are inclined to believe that the "canals" on Mars are natural markings rather than structures made by "men." As for the other planets, conditions in general seem unfavorable for

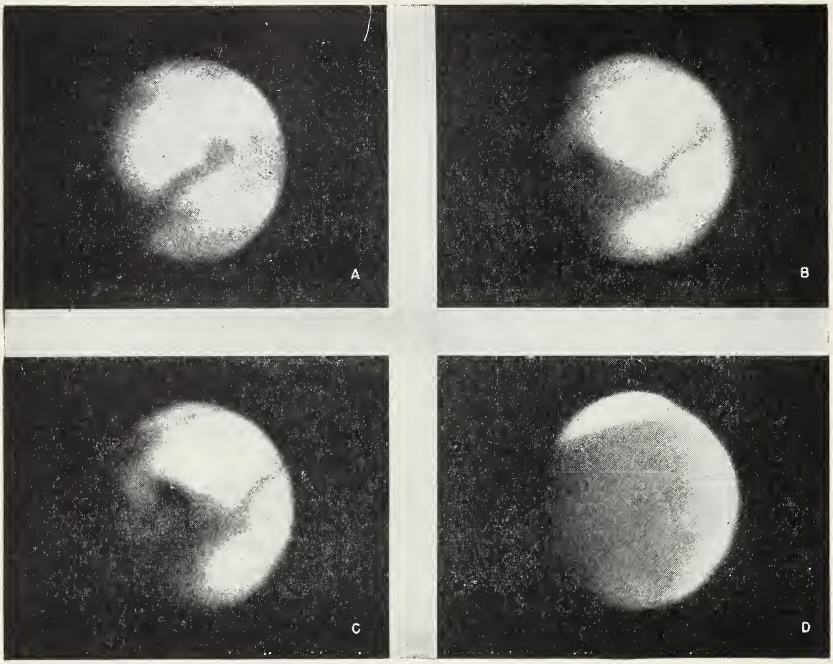

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Fig. 18–11. Four photos of Mars taken by the 100-inch telescope. Photos *A, B,* and *C,* taken several hours apart, show Mars' rotation.

the development of life. Some are too hot, some too cold; some lack an atmosphere, while others are covered by a poisonous atmosphere. Scientists believe, therefore, that if any other planet besides the earth supports life, that planet must be Mars.

14. Other solar systems? If other solar systems exist, we shall almost certainly never know of them. But astronomers believe that with the billions of stars known to exist in the universe, it would be strange indeed if our sun were the only one that has planets around it. At the great distances that separate the earth from the other stars, nonluminous planets would be impossible to see or detect in any way that we know of today.

HAVE YOU LEARNED THESE?

Meanings of: planet, planetoid, asteroid, satellite, meteor, meteorite, comet, photosphere, chromosphere, corona, sunspot, self-luminous, illuminated

Explanations of: a planet's year; a planet's day; evening stars; shape of planets' orbits; Saturn's rings; the light of planets, planetoids, satellites, meteors, comets; a comet's orbit; meteor showers; magnetic storms

Relations between: speed of rotation and a planet's shape; conditions on the planets and the possibility of life

Lists of: the nine planets according to their distance from the sun; the six types of bodies in the solar system; the members of the solar system arranged as self-luminous or illuminated

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) What is the solar system? What different kinds of objects are in it? (*b*) What keeps the members of the solar system in their orbits?

2. (*a*) How can planets be distinguished from stars? (*b*) Why do stars twinkle? Why don't planets twinkle? (*c*) Distinguish between self-luminous and illuminated bodies.

3. (*a*) Compare the composition of the sun and the planets. (*b*) Compare the planets in size.

4. (*a*) Name the planets in order of distance from the sun. (*b*) Which planets can be seen without a telescope? (*c*) Describe the orbits of the planets. In what way is Pluto's orbit different from the orbits of the other planets? (*d*) What is a year on a planet? What relation is there between a planet's distance from the sun and the length of its year? Why?

5. (*a*) What is a day on a planet? Compare the lengths of the days of the planets. (*b*) What effect does a planet's spinning have on its shape? What is an oblate spheroid?

6. (*a*) What are the planetoids? Where are they? How large are they? (*b*) How may the planetoids have been formed?

7. (*a*) Why are moons called satellites? (*b*) Which planets have no moons? (*c*) Which way do most of the satellites revolve? Name some exceptions. (*d*) What are Saturn's rings made of? Why do they shine? (*e*) Have all the satellites been discovered? Explain.

8. (*a*) Describe the appearance and composition of a comet. (*b*) The orbits of the comets are very eccentric. What does this mean? How does this explain the long intervals between the visits of a particular comet?

9. (*a*) What are meteors? What makes them light up? What are meteorites? What is a meteor crater? Give examples. (*b*) What is a meteor shower? What causes it? Give the names and dates of three well-known meteor showers. (*c*) How may meteor swarms have originated? (*d*) How has radar helped in the study of meteors?

10. (*a*) Describe the sun's photosphere, chromosphere, and corona. (*b*) What are sunspots? How large are they? (*c*) What are magnetic storms? (*d*) De scribe the sun's rotation.

11. (*a*) Why can Venus and Mercury never be seen at midnight? (*b*) What is meant by a morning star? an evening star? Why is Venus usually the morning or evening star? (*c*) Why can Mars, Jupiter, and Saturn be seen at night?

12. Explain how the "naked-eye planets" can be recognized in the sky.

13. Why does Mars seem more likely than any other planet to have life on it?

14. Discuss the likelihood that other solar systems exist.

GENERAL QUESTIONS

1. Even planets twinkle when they are close to the horizon. Why?

2. Why are seasons on Mars almost twice as long as those on the earth?

3. Compare Mars' Phobos with our own moon in relative size, distance from its planet, and time of revolution.

4. Phobos revolves from west to east around Mars faster than Mars rotates on its axis from west to east. In what direction does Phobos rise and set?

5. How may scientists have attempted to capture some of the gas in the tail of Halley's comet?

6. Halley saw the comet that is now named after him only once, in 1682. How was he able to prove that it was a regular visitor to the earth?

7. Compare meteors with comets. What evidence may lead scientists to believe that meteor swarms were once parts of comets?

8. Which planet other than Venus should show phases? Why?

9. Compare the sizes of sun, moon, earth, and Jupiter.

10. As an evening star, Venus can be seen only in the west; as a morning star, it can be seen only in the east. Why?

11. Compare the planets as to brightness.

12. The atmosphere of Mars appears to contain no oxygen. How does that affect the possibility of life on Mars?

STUDENT ACTIVITIES

1. Learning to identify the planets in the sky
2. Charting the nightly movements of the planets
3. Observing Venus, Mars, Jupiter, and Saturn through telescopes or field glasses
4. Making models of the planets to scale; showing their relative distances
5. Collecting photographs of members of the solar system

SUPPLEMENTARY TOPICS

1. Statistics of the Planets
2. Descriptions of the Planets and Their Satellites
3. The Discovery of Neptune and Pluto
4. Famous Planetoids
5. Famous Comets
6. Great Meteor Showers of History
7. How Sunspots Affect the Earth
8. Retrograde Motion of the Planets

See list of suggestions for further reading at the end of Chapter 17.

Chapter 19

OUR SATELLITE, THE MOON

THE MOON AND ITS MOTIONS

1. The face in the moon. Except for the meteor swarms whose path we cross from time to time, our moon is our nearest neighbor in space. Like the earth, the moon is a globe of rock, but it is much smaller than the earth. Its diameter is about 2160 miles as compared with ours of nearly 8000 miles. If a baseball is used to represent the moon, the earth is about the size of a basketball. Because of its small size, the moon's gravity force is only one-sixth as great as the earth's, and the moon is unable to hold gases. As a result it has no atmosphere and cannot support life.

The surface of the moon is clearly visible through telescopes. The "Man in the Moon" is only an illusion created by the pattern of sunlight and shadow on the lunar landscape during the time of full moon. The vast areas of deep shadow are large rough plains. They were called "seas" by early astronomers, but they contain no water. The bright elevated portion of the landscape consists largely of rugged, steep-walled mountains, only a few of which resemble the mountain ranges of the earth. For the most part the lunar mountains are great cratered peaks with diameters up to 150 miles. They resemble volcanic craters or meteor craters on the earth, but are much larger.

Since the moon has no atmosphere, it has no such defense against meteors as the earth has. And so it is very likely that many of its craters are of meteoric origin. With no atmosphere almost no

Fig. 19–1. Lunar landscape at last quarter, photographed by the 100-inch telescope. The largest craters have diameters of 150 miles.

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weathering or erosion can occur to wear down its jagged surface, and its only mantle rock covering consists of the fragments formed by exfoliation and by the shattering of meteors.

2. The moon's secret. The moon revolves around the earth like a watchful dog circling his master. Both moon and dog keep their faces toward the center around which they turn during their entire revolution. The result is that *we can never see the back of the moon.* The explanation is that the moon *rotates* exactly the same number of degrees on its axis as it *revolves* in its orbit around the earth. For example, after it has revolved one-fourth of the way around the earth, it must also have rotated one-fourth of a turn on its axis. When it has completed one revolution, it must also have completed one rotation. If the moon did not rotate at all, its back would be seen when it had gone half way around the earth from its starting position. Try these two "experiments" yourself. First walk around a friend without rotating at all—keep facing the same direction throughout. Does he see your back? Now walk around him with your face toward him all the time. What did you have to do to keep facing him?

Actually we see a little more than half of the moon during the month of its revolution, because the moon "wobbles" a bit as it revolves around the earth.

3. The moon's orbit. If you could sit on a ray of light and ride to the moon, you would reach it in 1¼ seconds. In 1946 United States Army Signal Corps experimenters bounced a radar beam off the surface of the moon and back to the earth. Traveling at the speed of light, it made the round trip in 2½ seconds.

The moon revolves from west to east

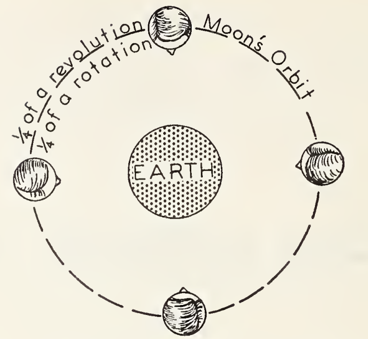

Fig. 19–2. Why we see only one side of the moon. As the moon revolves around the earth, it keeps the same side toward us by rotating at the same rate.

around the earth in an elliptical orbit at an average distance of nearly 240,000 miles. (In the sky the moon seems about the same size as the sun, for the sun, with a diameter about 400 times the diameter of the moon, is about 400 times as far away as the moon.) The moon takes 27⅓ days to go all around its orbit. This 27⅓-day period is called its *period of revolution.* As explained in Topic 2, its *period of rotation* is exactly the same length, thus permitting us to see only one side of the moon.

When the moon is nearest to the earth in its orbit, it is said to be at *perigee* (*pehr* ih jee). (*Peri* means near; *ge*, earth.) This may be as close as 221,-000 miles. At its farthest point, *apogee* (*ap* uh jee) it may be 253,000 miles away. The moon's orbit is not in the

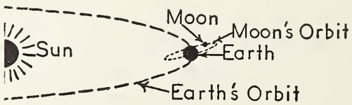

Fig. 19–3. The moon's orbit is tilted. As the moon revolves around the earth, it passes both above and below the plane of the earth's orbit.

same plane as the earth's orbit, but is inclined to it at an angle of about 5 degrees. This fact is of great importance in determining how often eclipses occur. See Topic 11.

4. Moonrise. The moon rises in the east and sets in the west every day, much as the sun does, and for the same reason. This motion through the sky is an apparent one, caused by the daily rotation of the earth from west to east on its axis. If the moon did not revolve around the earth, we would see it in the same place in the sky at a given time each day. But while the earth makes one turn on its axis, the moon revolves in the same direction, west to east, about $\frac{1}{27}$th of its path around the earth (about 13 degrees) and is no longer where it was in the sky the day before. To "catch up," the earth must now rotate the additional 13 degrees on its axis. This takes about 50 minutes (about $\frac{1}{27}$th of 24 hours). If we look for the moon on the eastern horizon where it rises, we notice that the moon appears there about 50 minutes later each night, and so we say that the moon rises 50 minutes later each night. As it rises later, it also sets later (Figure 19–4).

Since the moon rises later each night, in the course of a month it appears at a particular place in the sky at practically all times of day as well as night. When it is on the same side of the earth as the sun, it appears largely in the daytime sky. When it is on the side opposite to the sun, it appears largely in the nighttime sky.

5. The moon's phases. In Topic 2 it was explained that only one side of the moon ever faces the earth. If the moon, like a star, were self-luminous, we would see all of this face as a full moon every day, though it would be less conspicuous in the daytime than at night. But the moon has no light of its own. Like the earth, it receives its light from the sun, and being a solid rock globe, only one half of it can be illuminated at a time. The sun lights up the half of the moon that faces it, but except for a short time each month, this is obviously not the half that is kept constantly turned toward the earth. In fact, the half facing us varies in illumination each night, changing in about two weeks from complete darkness to full light, and then declining for about two weeks until it is entirely dark again. These different aspects of the moon's appearance, as seen from the earth, are known as its *phases.*

Figure 19–5 shows the moon at eight evenly spaced points in its orbit. Each point is about half a week away from the next. In every case the half of the moon that faces the sun is fully illuminated. Looking from the earth, however, we see different amounts of the illuminated half at each of the eight phases. What we see in the sky is

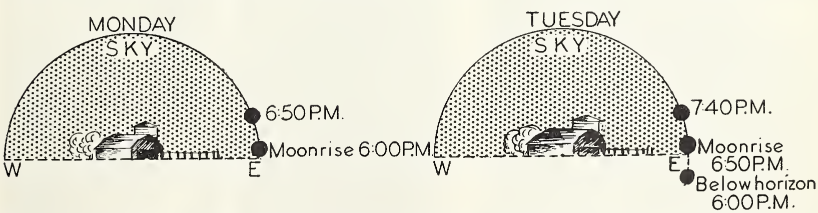

Fig. 19–4. The moon rises about 50 minutes later each night. This diagram shows what that means to an observer watching the moon on two successive nights.

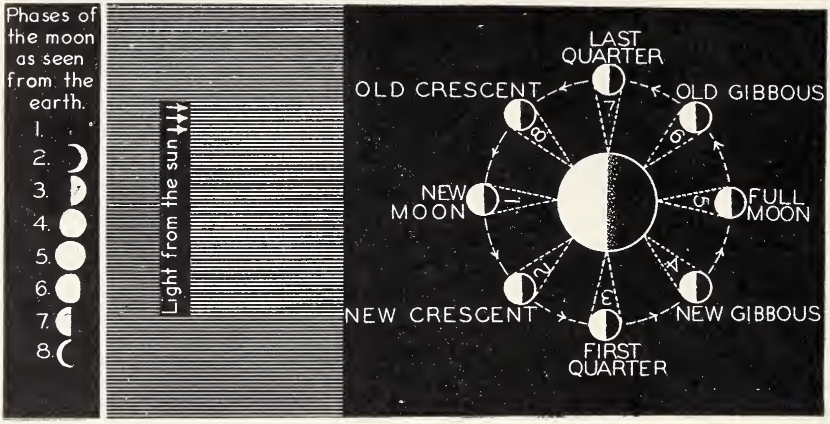

Fig. 19–5. Phases of the moon. The diagram at the right shows the actual illumination of the moon at its eight phases. The lines drawn to the moon show the part of the moon seen from the earth at each phase. The sketch at the left shows what the moon looks like to an observer on the earth at each phase.

shown in the sketches that are drawn in the column at the left. Remember, the whole "Man in the Moon" faces us at all times, but it is only at full-moon phase that he is all "lit up."

From new moon to full moon, more and more of the moon's illuminated half faces the earth and the moon is said to be *waxing*. From full moon to new moon, less and less of the moon's illuminated half faces the earth, so it is said to be *waning*. All the phase names are self-explanatory, except *gibbous* (*gib* us), which might be described as "lop-sided."

At new moon, the entire dark side of the moon faces us and we see nothing. At the crescent phases, only one edge of the side facing us is illuminated, and we see that edge as a crescent. At the quarter phases, the side facing us is half light, half dark. At the gibbous phases, only a dark crescent prevents our moon from being fully illuminated. At the

Fig. 19–6. Three phases of the moon: full moon, old crescent, last quarter.

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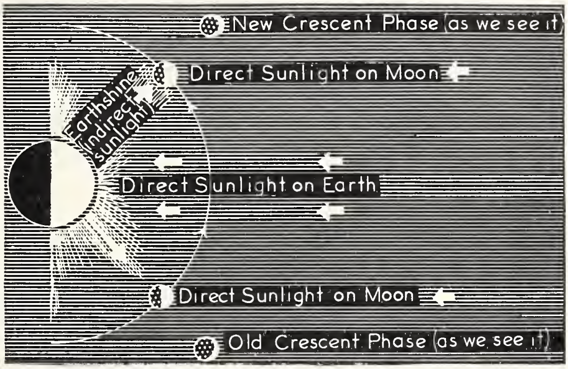


Fig. 19–7. How earthshine lights up the dark side of the crescent moon. Sunlight reflected from the daylight side of the earth weakly illuminates the side of the moon that does not face the sun.

full phase, the side facing us is fully illuminated.

6. Moonshine and earthshine. At the crescent phases of the moon we see the brightly illuminated crescent shining in direct sunlight. In addition, however, we cannot help but notice that all the rest of the moon is also visible, although dimly. This portion of the moon, though not facing the sun, is being illuminated indirectly *by sunlight that is reflected from the daytime side of the earth to the dark side of the moon,* as shown in Figure 19–7. This dim glow of the moon is known as *earthlight* or *earthshine.*

7. Daytime moon. As explained in Topic 4, the moon is in the sky by day as much as by night, though it is less easily noticed in daylight. From Figure 19–5 it is easy to see at what phases the moon is a daytime moon, a nighttime moon, or both. If the moon is on the same side of the earth as the sun, it will be in the sky mostly in the daytime. This is true at the new and crescent phases. At the quarter phases it will be in the sky about as many daylight hours as night hours. At the full and gibbous phases the moon is on the side of the earth opposite to the sun, so it is almost entirely a nighttime spectacle. These are the phases that are best known to most of us.

Further study of Figure 19–5 will enable you to work out the approximate times of the rising and the setting of the moon at each phase. It is interesting to check your times with the times given by the newspapers or almanacs. With their help you will be able to locate the moon in the daytime sky.

8. Outdoor laboratory. The positions of moon, earth, and sun that produce the various phases can really be seen outdoors. For example, Figure 19–5 shows the earth directly between the moon and the sun at full-moon phase. Standing outdoors at sunset on the day of the full moon, an observer on the earth sees the sun setting in the west, the moon rising in the east, and himself directly between them. At first-quarter phase he may see the moon in the south as the sun sets in the west, while he himself forms the corner of the right triangle on the earth. This is just what the diagram shows. The other phase

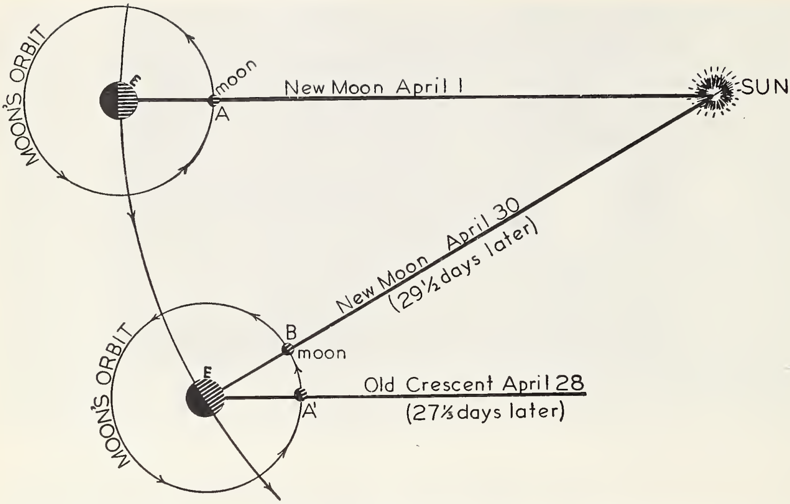


Fig. 19–8. Though the moon's revolution period is 27⅓ days, it requires 29½ days to go from new moon to new moon. In 27⅓ days the moon revolves from *A* to *A'*, but because of the earth's revolution this is no longer a new moon position. To reach new moon position again, the moon must reach *B*, which takes about 2 more days.

positions can be observed in the same way. The observer will also notice that the lighted side of the moon always faces the sun.

9. Lunar month. The early Roman calendar was based on the motions of the moon, from which we derive the name *month*. The *lunar month*, measured from new moon to new moon, is 29½ days long. This is more than 2 days longer than the moon's period of revolution, because while the moon is revolving around the earth, the earth is also moving forward in its orbit around the sun. This makes it necessary for the moon to revolve a little more than once around its orbit before it can again be in line with both earth and sun to repeat the new-moon phase. See Figure 19–8.

THE MOON AND ECLIPSES

10. Earth's shadow on the moon. As the earth revolves around the sun it casts its shadow off into space. This shadow, pointing away from the sun on the nighttime side of the earth, consists of two parts, an *umbra,* or total shadow, and a *penumbra* (peh *num* bruh), or partial shadow. The umbra is an enormously long narrowing cone which reaches its apex (tip) at a distance of about 860,000 miles from the earth. The penumbra, widening instead of narrowing, stretches endlessly off into space. When the earth's shadow falls on the moon, an *eclipse of the moon* takes place. The eclipse is *total* if the moon is entirely in the umbra, and *partial* if the moon is partly in the umbra, or in the penumbra (Fig. 19–9). (Penumbra shadows are hardly noticed on the moon.)

11. Time of lunar eclipse. The only phase at which the earth's shadow can fall on the moon is full moon. An eclipse of the moon would take place at full-moon phase every month if the moon's orbit were in the same plane as

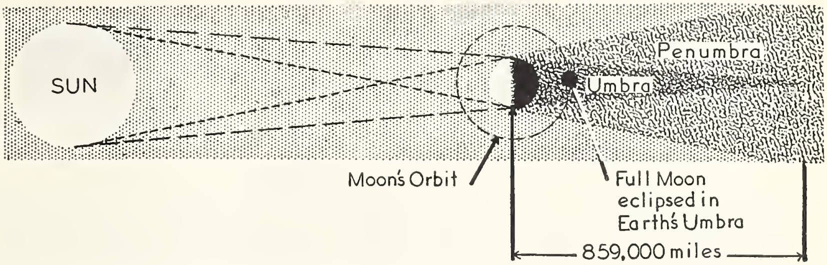


Fig. 19–9. A total eclipse of the moon (lunar eclipse) occurs when the full moon passes through the umbra of the earth's shadow.

the earth's orbit. But since the moon's orbit is inclined 5 degrees to the earth's orbit (see Topic 3), *lunar eclipses* can take place only if full moon comes when the moon crosses the plane of the earth's orbit, or is close to it. This happens between two and five times each year, but no more than three of these times are total eclipses.

At the moon's distance of about 240,000 miles from the earth, the earth's umbra is almost 6000 miles in diameter, or almost three times as wide as the moon. If the moon goes through the center of the umbra, the eclipse may be total for almost two hours.

12. Seeing a lunar eclipse. There are many opportunities within a lifetime to see a total lunar eclipse. On the average, at least one such eclipse takes place every year, and the entire nighttime half of the earth is in a position to see it. Added to this are the parts of the world that miss the beginning of the eclipse but rotate into view while the eclipse lasts. So, if the weather is good, more than half the world can see each lunar eclipse.

The earth's umbra is not completely dark, because the earth's atmosphere acts like a lens and bends some sunlight into the shadow cast by the solid earth. As a result, the moon has a dusky red color in the umbra, instead of being completely blacked out.

Lunar eclipses can be forecast for years in advance, it being common practice nowadays to use the new electronic calculating machines for such problems. The times of future eclipses may be found in astronomy publications and in the *Nautical Almanac.*

13. Moon's shadow on the earth. Like the earth, the moon casts its shadow into space. The moon's umbra has an average length of 232,000 miles, barely long enough to reach the earth at perigee but not long enough to reach it at apogee. Even at perigee, it is only the tip of the umbra that touches the earth, with a maximum width of just 167 miles. The penumbra is much wider, of course, since it becomes larger as it extends away from the moon. When the moon's shadow falls on the earth an *eclipse of the sun* takes place. Where the umbra falls, the eclipse is *total;* where the penumbra falls, the eclipse is *partial.* (See Figure 19–10.)

14. Time of solar eclipse. An eclipse of the sun takes place when the moon "gets in the way of the sun." If the moon hides the sun completely, the sun is totally eclipsed; if the moon covers only a part of the sun, the sun is partially eclipsed. The only phase at which this

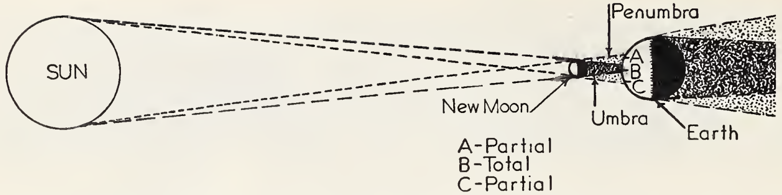


Fig. 19–10. A total eclipse of the sun (solar eclipse) occurs when the new moon crosses the plane of the earth's orbit and casts its shadow on the earth. The eclipse is total in the moon's umbra and partial in its penumbra.

can happen is new moon. An eclipse of the sun would take place at new-moon phase every month were it not for the inclination of the moon's orbit. As it is, solar eclipses occur from two to five times a year, whenever the moon crosses or comes close to the plane of the earth's orbit at new moon. Three of these eclipses may be total.

As mentioned above, the narrow tip of the umbra that barely reaches the earth's surface is never more than 167 miles wide; it may be much less. This means that only a very small part of the earth can see any solar eclipse as a total eclipse. (The much larger area on which the penumbra falls sees the same event as a partial eclipse.) Nor does the total solar eclipse last very long, for the moon's revolution causes the narrow shadow to race across the earth at a speed of more than 1000 miles an hour. At any one spot, a total solar eclipse can never be seen for more than 7½ minutes even under the most ideal arrangement of sun, moon, and earth. The narrow track made on the earth's surface by the eastward-moving shadow of the moon is called the *eclipse path.* It may be thousands of miles long.

15. Seeing a solar eclipse. While solar eclipses happen at least as often as lunar eclipses, the area covered by the umbra at each eclipse is so small that any one spot on the earth averages only one total eclipse in 300 years. It is easy to see, therefore, why a total solar eclipse is such a rare sight for any one person. Astronomers travel thousands of miles in well-planned "eclipse expeditions" to make studies of the sun's corona and other features which are best seen when the sun's photosphere is covered by the moon. The next total solar eclipse visible in any part of the United States takes place in 1963.

A solar eclipse begins when the moon is first seen to come across the western edge of the sun. It ends when the moon disappears from the eastern edge. From start to finish, the entire eclipse may last four hours. Only during the few minutes of totality is it safe to view the sun without a protective filter. At totality the chromosphere and corona can be seen surrounding the blackened face of the sun, while in the darkened sky it is sometimes possible to see bright stars and planets with the naked eye. See Figure 18–9.

16. Annular eclipse. *Annular eclipses* of the sun occur a little more often than total eclipses. In an annular eclipse, the moon is in the same position as in a total solar eclipse, but its umbra does not reach the earth. The result is a *partial eclipse* with a "special feature." In those parts of the world that are directly in the center of the penumbra, the moon appears to cover all but a thin

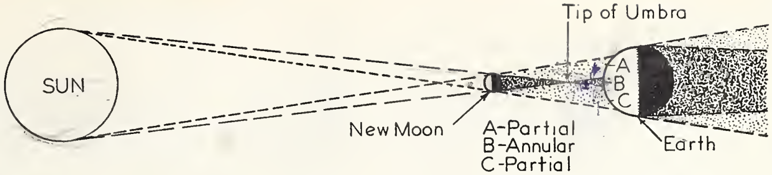


Fig. 19–11. An annular (ring) eclipse of the sun occurs when the new moon's umbra fails to reach the earth. A partial eclipse results. To observers who are near the center of the penumbra the outer edge of the sun is seen as a ring.

outside ring of the sun's photosphere. (The term "annular" comes from the Latin word *annulus*, which means "ring." Do not confuse "annular" with "annual," which means "yearly.") In other parts of the penumbra the eclipse is seen as an ordinary partial one.

SUN, MOON, AND TIDES

17. The moon and the tides. The chief physical effect of the moon on the earth is that it causes the ocean tides. There are several facts that show the connection between the moon and the tides. The tides rise 50 minutes later each day, on the average, just as the moon does. Very large tides occur at times of new and full moon, while very small tides occur at times of first and last quarter moon.

18. Cause of tides. The moon's gravity pull on the earth is the chief cause of tides. The closer two objects are, the greater is the pull of gravity between them. In this case, it means that the moon's pull on the near side of the earth is greater than its pull on the center of the earth or the far side of the earth. In Figure 19–12 below, the moon attracts the ocean water at H_D more than it attracts the solid earth's center at C, causing the waters to rise or bulge in a "high tide." This is known as the *direct high tide*. But the moon attracts the ocean waters at H_I even less than it attracts C, leaving the waters bulging away from the earth on that side. This high tide is known as the *opposite* or *indirect high tide*. At L and L' the ocean has become lower than average, for waters have moved to the high-tide bulges. At L and L', then, there are low tides.

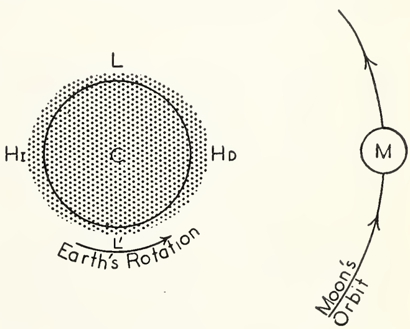


Fig. 19–12. The moon and the tides. The moon causes high tides at H_I and H_D, and low tides at L and L'.

Briefly it can be said that tides are caused by differences in the moon's gravity pull on the solid earth and its ocean areas.

19. Rise and fall of the tides. *The rise and fall of the tides are caused by the earth's rotation on its axis.* As the earth turns on its axis, points H_D and H_I (Figure 19–12) turn until they reach low-tide positions, while L and L' move into high-tide positions. This quarter-

turn of the earth would take 6 hours, but the moon's revolution around the earth at the same time makes it necessary for the earth to turn an extra 13 minutes to line up L and L' with the moon. In this period of 6 hours 13 minutes, the tides gradually fall from high to low at H_D and H_I, and rise from low to high at L and L'. This goes on constantly as the earth rotates, with the tides rising and falling about every 6 hours and 13 minutes, and four such movements taking place in about 24 hours and 50 minutes. This means that both the tides and the moon come 50 minutes later each day, and for the same reason—because the moon revolves around the earth.

Here is a sample timetable of the tides at any particular place:

Tide	*Date*	*Time*	*Interval Since First High Tide*
High	July 4	1:00 A.M.	
Low	July 4	7:13 A.M.	6 hr. 13 min.
High	July 4	1:25 P.M.	12 hr. 25 min.
Low	July 4	7:38 P.M.	18 hr. 38 min.
High	July 5	1:50 A.M.	24 hr. 50 min.

The times given here are averages. In actual observations they are much more irregular. Tide timetables may be found in the fishing or shipping columns of daily newspapers and in almanacs.

20. The sun's influence. The sun has the same kind of effect on the earth's waters as the moon has, but because of its greater distance this effect is only about half as great as the moon's. This means that while the moon is the chief maker of tides, the sun can help or hinder the moon's effects. Tides are always high on the parts of the earth in line with the moon, and low on the parts that are at right angles to the moon. But when the sun is in line with the moon, its effect is added to the moon's. When the sun-earth line is at right angles to the moon-earth line, the sun's effect is opposed to the moon's.

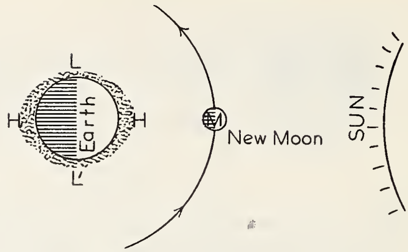


Fig. 19–13. Spring tides occur when sun, moon, and earth are in line (at either new or full moon). At these times of the month, high tides are highest and low tides are lowest.

At new-moon and full-moon phases both sun and moon are causing high tides and low tides at the same places on the earth. This results in unusually high high-tides and unusually low low-tides. The *tidal range*, defined as the difference between the level of high tide and the level of low tide, is very large at these times. These tides are called *spring tides*, perhaps because the waters "spring so high." Remember, they occur twice every month and have nothing to do with the spring season.

At first-quarter and third-quarter phases the sun is in a position where it

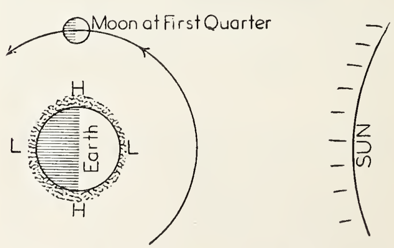


Fig. 19–14. Neap tides occur when sun, earth, and moon form a right angle (at either first or last quarter phase). At these times of the month, the tides rise and fall less than at any other time.

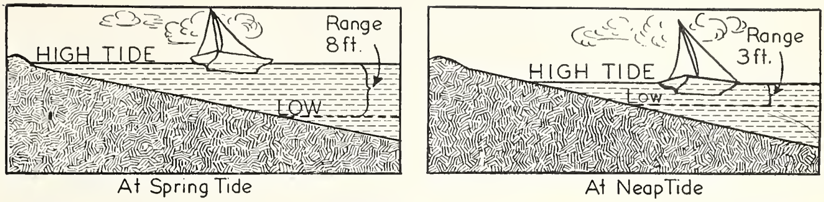


Fig. 19–15. Tidal range is large at spring tides (high high-tides and low low-tides). Tidal range is small at neap tide (low high-tides and high low-tides). The exact range of the tides varies with different parts of the world.

raises the moon's low-tide levels and lowers the moon's high-tide levels. This results in high tides that are not very high, and low tides that are not very low. The tidal range is very small at these times. These tides are called *neap tides* (neap means "scanty").

21. Tidal range and shorelines. The amount of rise and fall of the tide varies not only with the phase of the moon and the distance of the moon from the earth, but also with the many physical features of the ocean floor and the shorelines against which the tides rise and fall. In the open ocean the tidal range averages 2 or 3 feet. In V-shaped bays which become narrower from mouth to head (inland), the incoming tide may be compressed to an enormous height, an outstanding example being the 60-foot spring tide in the Bay of Fundy on the coast of Nova Scotia. In bays that become wider from mouth to head, the tidal range may be very small. In the Gulf of Mexico, for example, the tidal range is usually less than 2 feet.

Large inland lakes and seas, like the Great Lakes and the Caspian Sea, have much smaller tides than the ocean, while small lakes show practically no tides at all.

22. Flood tide, ebb tide, and slack water. The incoming or rising tide is often called the *flood tide.* The outgoing or falling tide is known as the *ebb tide.* The tide rises for about 6 hours and 13 minutes and falls for about the same length of time. At the moment of high tide the ocean waters appear to stand still briefly before the tide begins to fall. This period is known as *slack water.* Slack water also occurs when low tide is reached, lasting for a few moments before the tide begins to rise again.

HAVE YOU LEARNED THESE?

Meanings of: perigee, apogee, waxing, waning, umbra, penumbra, lunar month, spring tide, neap tide, tidal range, flood tide, ebb tide, slack water

Diagrams of: the phases of the moon; lunar eclipse; solar eclipse; annular eclipse; spring tide; neap tide

Explanations of: the moon's surface features; why only one side of the moon is seen; why the moon rises later each night; why the moon has phases; earthshine; the lunar month; lunar eclipse; solar eclipse; annular eclipse; why few people see a total solar eclipse

Relations between: sun, moon, and tides; tides and phases; tidal range and shorelines

Numbers: moon's period of revolution, period of rotation, diameter, distance from the earth

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. Describe the moon as to size and surface features. Explain its lack of atmosphere and mantle rock.

2. Explain why we can see only one side of the moon.

3. Describe the moon's motions, giving the direction and period of its rotation and revolution, the shape of its orbit, its average distance from the earth, its distance at perigee and apogee, and its orbit's inclination.

4. Why does the moon rise in the east and set in the west? Why does it rise about 50 minutes later each night?

5. Why isn't the moon full all the time? Explain its phases, using a diagram.

6. Explain what earthshine is.

7. At what phases is the moon in the sky chiefly at night? in the daytime? half and half?

8. Explain how the sky may be used as a laboratory for showing how phases are caused.

9. What is a lunar month? Why is it 2 days longer than the moon's period of revolution?

10. Describe the earth's shadow. How is it related to eclipses of the moon?

11. (*a*) At what phase does a lunar eclipse occur? Why does it not occur every month? (*b*) How long may a total lunar eclipse last? (*c*) Make a diagram showing how a lunar eclipse occurs.

12. (*a*) How much of the world can see each lunar eclipse? Why? (*b*) Why isn't the moon completely darkened in a total lunar eclipse?

13. Describe the moon's shadow and its relation to eclipses of the sun.

14. (*a*) At what phase does a solar eclipse occur? Why doesn't it occur every month? (*b*) How long can a total solar eclipse last? Why? (*c*) What is the eclipse path? (*d*) Make a diagram of a solar eclipse.

15. (*a*) Why are total solar eclipses such rare sights even though they happen almost every year? (*b*) Why do astronomers observe total solar eclipses? (*c*) Describe a total solar eclipse.

16. (*a*) What is an annular eclipse? How does it happen? Where does its name come from? (*b*) Make a diagram showing an annular eclipse.

17. What facts indicate a connection between the moon and the tides?

18. (*a*) Explain how the moon causes the tides. (*b*) Make a diagram showing where high and low tides are in relation to the moon's position.

19. (*a*) Explain why tides rise or fall every 6 hours 13 minutes. (*b*) Explain why the tides come 50 minutes later each day.

20. (*a*) How does the sun affect tides? Explain. (*b*) Define tidal range. (*c*) What are spring tides? How and when do they occur? (*d*) What are neap tides? How and when do they occur? (*e*) Show spring and neap tides in diagrams.

21. Compare the tidal range in the open ocean with that of various shorelines and of inland seas and lakes.

22. Explain what is meant by: flood tide; ebb tide; slack water.

GENERAL QUESTIONS

1. When the moon passes in front of a star or planet in the sky, the star disappears from view all at once, rather than gradually. How does this show that the moon has no atmosphere?

2. Why is the moon "defenseless" against meteors?

3. If the moon revolved from east to west, how would that affect its rising?

4. Make a diagram to show that very little earthshine can strike the moon at a gibbous phase.

5. Work out the approximate times of moonrise and moonset for the phases shown in Figure 19–5.

6. Using a diagram of the moon's phases, prove that the only phase at which

the earth's shadow can fall on the moon is full moon.

7. In Topic 11 it is stated that the earth's umbra is about 6000 miles in diameter where the moon crosses it. Prove this by geometry.

8. What determines how long a total eclipse will last?

9. It was once thought that there was a planet closer to the sun than Mercury. Why were observations of solar eclipses necessary to disprove this?

10. Can a solar eclipse start as an annular eclipse and then become total? Explain.

11. Direct and indirect high tides are about the same height when the moon is in the plane of the earth's equator, but may be very unequal when the moon is above or below the equator. Show this in a diagram.

12. (*a*) What combination of factors (moon's distance from earth, earth's distance from sun) would produce the largest spring tides? (*b*) What combination would produce the smallest neap tides?

STUDENT ACTIVITIES

1. Observing the moon through telescopes, binoculars, and the naked eye
2. Observing and recording the time of moonrise and moonset at various phases of the moon
3. Collecting photographs of the moon
4. Demonstrating the moon's equal periods of rotation and revolution
5. Building a model to show the inclination of the moon's orbit to the plane of the earth's orbit
6. Observing the positions of sun, earth, and moon at various phases
7. Observing earthshine
8. Demonstrating why the moon rises later each day
9. Demonstrating why a lunar month is longer than the moon's period of revolution
10. Demonstrating an "eclipse" of sun or moon with globes and electric lights
11. Observing eclipses
12. Recording and plotting the time of the tides
13. Observing the time of tides
14. Observing the relation of tidal range to the moon's phases, or plotting them from data

SUPPLEMENTARY TOPICS

1. The Map of the Moon
2. Lunar Craters
3. The Origin of the Moon
4. Coming Lunar Eclipses
5. Coming Solar Eclipses
6. Local Newspaper Accounts of Recent Eclipses
7. Tidal Bores and Races
8. High-Water Interval
9. Tides in Seas and Lakes

See lists of suggestions for further reading at ends of Chapters 17 and 35.

Chapter 20

THE EARTH, ITS MOTIONS, AND ITS SEASONS

1. The planet Earth. Third planet from the sun, the earth is so placed in the solar system that it receives neither too little nor too much of life-giving sunlight. Nor does it, like the moon, turn so slowly on its axis that its day reaches fearful extremes of heat and cold. Alone of all the planets, its atmosphere includes a generous proportion of the oxygen essential to our form of life. No other planet has an ocean from which rain clouds may form to carry vital moisture over its lands. With the possible exception of Mars, the earth seems to be the only planet fitted for the existence of life.

Fig. 20–1. Photograph of the planet Earth from 100 miles up, showing its curved surface. Taken by an automatic camera in a V-2 rocket. Compare this photo with that of the moon in Figure 19–1.

United States Army Air Force

2. The shape of the earth. Like all the planets, the earth is ball-shaped, or spherical. Modern proof of this shape is supplied by photographs taken at very high altitudes from stratosphere balloons and ionosphere rockets. But even thousands of years ago the curved shadow of the earth on the moon (during lunar eclipses) was regarded as proof that the earth was a sphere. Also, the fact that different constellations were seen in northern and southern parts of the world was taken to indicate that the earth was curved.

The weight of an object is a measure of the force with which gravity pulls it toward the earth's center, and it depends on the distance of the object from the center of the earth. Thus, the fact

that an object weighs almost the same in all parts of the world means that it is at about the same distance from the earth's center; the earth is therefore spherical in shape.

3. The earth's revolution. Imagine an oval-shaped track around which a runner is going at a steady pace. Inside the oval, a little to one side of center, the coach stands and shouts instructions to his pupil. In similar fashion the earth travels in its track around the sun. The earth's oval path around the sun is called its *orbit;* its "tour" around the sun is called its *revolution;* and the flat surface in which its orbit lies is known as the *plane of the orbit.* In this 600,000,000 mile orbit the earth revolves from *west to east* at a steady speed of *1 lap per year,* or about 66,000 miles every hour. Measured as an angle, the full turn of 360 degrees in 365¼ days is at the rate of about *1 degree per day.*

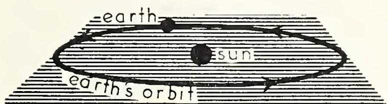


Fig. 20–2. The level surface in which the earth revolves around the sun is known as "the plane of the earth's orbit."

4. The earth's orbit. Since the earth's orbit is an oval, or *ellipse* (not a circle), the distance between the earth and the sun constantly changes as the earth revolves around the sun. The average distance between the earth and the sun is about 93,000,000 miles. The sun is 1,500,000 miles north of the orbit's center, at a point called the *north focus* of the orbit (see Figure 20–3). The earth is therefore nearest to the sun at the north end of the orbit, this point being known as *perihelion* (pehr ih *heel* y'n). (*Peri* means near; *helios,* sun.) The earth passes this point each year about January 1. The earth is farthest from the sun at the opposite end of the orbit, called *aphelion* (uh *fee* li y'n). (*Ap* mean from; *helios,* sun.) The earth

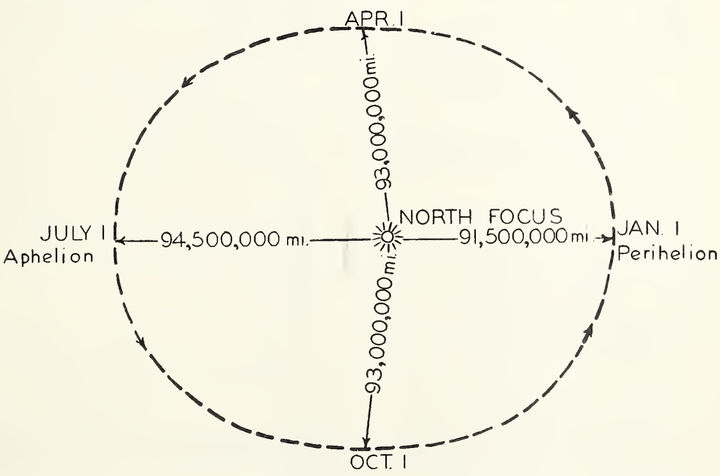


Fig. 20–3. A top view of the earth's orbit shows its elliptical shape. The sun is about 1,500,000 miles from the center of the ellipse, and in January the earth is nearer the sun than at any other time.

passes the aphelion each year about July 1.

If the earth's orbit is drawn in its true proportions, it is seen to be very close to a circle. In Figure 20–3 its "ovalness" is greatly exaggerated in order to emphasize the features of the orbit described above.

5. The earth's rotation; its axis. Everyone is familiar with the spinning of a top or the turning of a merry-go-round. Such motion around a real or imaginary *axis,* or line inside of itself, is called *rotation.* Imagine a gigantic top 8000 miles high and 25,000 miles around its middle leaning over a bit and spinning fast enough to swing its 25,000-mile circumference completely around in 24 hours. This gives a general idea of how the earth rotates.

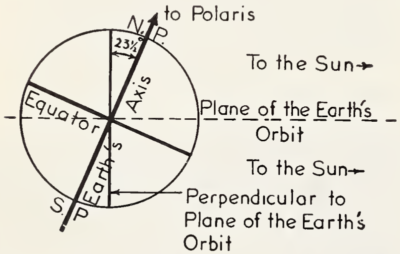


Fig. 20–4. The earth's axis is inclined 23½° from a perpendicular to the plane of its orbit.

The spherical earth, almost 8000 miles in diameter and almost 25,000 miles in circumference, *rotates from west to east* on its axis, making one complete turn every day. With reference to the plane of the earth's orbit (see Topic 3) the earth's axis is not upright; it leans over, like the axis of the top described above, at an angle of 23½ degrees from the vertical. This is usually stated as follows: *The earth's axis is inclined 23½ degrees from a perpendicular to the plane of its orbit.* This tilt is the *inclination of the earth's axis.*

The ends of the axis are known as the *North Pole* and *South Pole.* The north end of the axis points in the heavens to a moderately bright (second-magnitude) star which has been named *Polaris,* the *Polestar,* or the *North Star.* In the Southern Hemisphere sky there is no bright star near the South Pole.

The circle drawn around the earth midway between the poles is called the *Equator.* The half of the earth north of the Equator is called the *Northern Hemisphere;* the half south of the Equator is the *Southern Hemisphere.*

6. The earth's rotation. The rate of the earth's rotation may be expressed in degrees per hour or in miles per hour. All points on the earth rotate one turn or 360 degrees in 24 hours. Dividing 360 by 24, we see that the earth's angular rate of rotation is 15 degrees per hour or 1 degree of turn every 4 minutes. The number of miles any given point on the earth turns in 24 hours depends on its distance from the Equator. Places along the Equator turn 25,000 miles in 24 hours, or a little over 1000 miles per hour. New York City, which is almost halfway from the Equator to the North Pole, turns only 19,000 miles in 24 hours, or about 800 miles an hour. In general, the nearer a place is to one of the poles, the slower is its rate of rotation in miles per hour. At the North and South Poles there is no rotation.

Figure 20–5 shows a "north polar" view of the earth, that is, a view from above the North Pole. In such a view the earth is seen to rotate in a direction opposite to that of the hands of a clock. This is described as *counterclockwise* rotation.

7. Rotation and the earth's shape. As explained in the chapter on the plan-

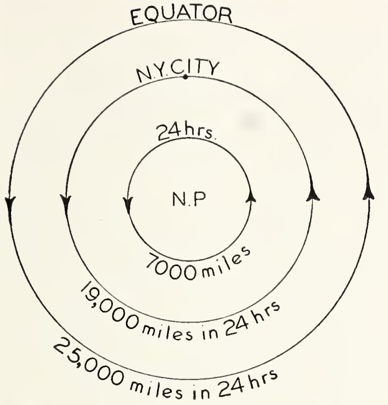


Fig. 20–5. This north polar view of the earth shows its counterclockwise rotation. Although all points on the earth rotate around the axis once in 24 hours, those farther from the Poles move greater distances in that time.

ets, the centrifugal force of rotation is greater at a planet's equator than at its poles; this causes a bulging at the equator and a flattening at the poles. A sphere flattened in this manner is called an *oblate spheroid.* The diameter of the

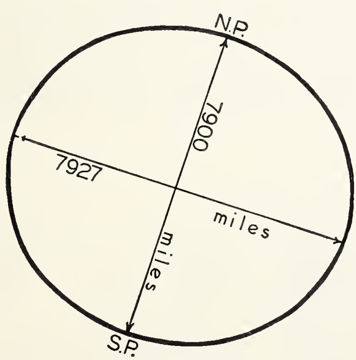


Fig. 20–6. The earth's rotation makes it an oblate spheroid, though much less oblate than Jupiter. (See Figure 18–3.) The equatorial diameter is 27 miles longer than the polar diameter.

earth from pole to pole (*axis* or polar diameter) is 7900 miles, whereas its diameter at the Equator (equatorial diameter) is 7927 miles, a difference of 27 miles. Since this difference is only about 1/300th of the whole diameter, the earth is practically a true sphere. In Figure 20–6 its oblateness is greatly exaggerated.

DAY AND NIGHT

8. Why day and night. The explanation of day and night really involves four problems: (1) why the earth has day and night; (2) why day and night alternate; (3) why day and night are unequal in length on all but two days of the year; (4) why day and night change in length from day to day.

Daylight is sunlight. Even when the sky is completely covered with clouds, the light that illuminates the earth is the sunlight that penetrates the clouds. Since the earth is a solid sphere, only one half of its surface can be illuminated by the sun at any one moment. That half is in daylight; the other half is in the darkness of nighttime, relieved only by the light of stars, planets, and the moon. *Day and night exist on the earth because the earth is a solid sphere which receives its light from the sun.*

9. Why day and night alternate. If the earth neither rotated nor revolved, one side would always have day and the other side would always have night. But since the earth rotates on its axis once every 24 hours, day and night alternate for most places on the earth in every 24-hour period.

In the north polar view of the earth shown in Figure 20–7, the earth makes one rotation (from west to east, or counterclockwise) every 24 hours. Twelve hours are spent in darkness, twelve in sunlight. Line *PR* represents sunrise at

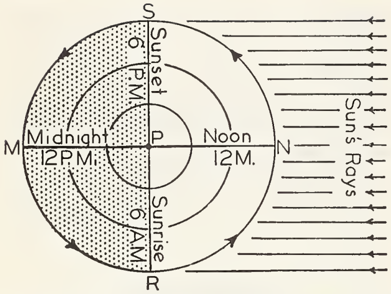


Fig. 20–7. The earth's rotation makes day and night alternate during every 24-hour period for most places on the earth.

6 A.M.; line *PS* is the sunset line, reached 12 hours later at 6 P.M.; line *PN*, halfway from sunrise to sunset, represents noontime at 12 M; line *PM*, halfway from sunset to sunrise, "in the middle of the night," represents midnight at 12 P.M. As each point on the earth reaches line *PR*, the sun comes into view and sunrise occurs. As rotation continues, each point goes through its day. *Day and night alternate because of the earth's rotation.*

10. Why day and night are not equal. If the earth's axis were perpendicular to the plane of its orbit, all parts of the world would have about 12 hours of daylight and 12 hours of darkness every day of the year. But the earth's axis is inclined, and one hemisphere usually leans toward the sun more than the other. Thus one hemisphere has more than 12 hours of daylight while the other hemisphere has less than 12 hours of daylight. The more one hemisphere leans toward the sun, the more unequal day and night become. (As an extreme case, if the North Pole were pointed straight at the sun, the whole Northern Hemisphere would have 24 hours of daylight, and the Southern Hemisphere would have 24 hours of darkness.) Furthermore, the inequality of day and night is greater near the poles than near the Equator.

In Figure 20–8*a* the earth is shown as it would be if its axis were upright. Day and night would always be equal in length throughout the world. In Figure 20–8*b* the earth is shown with its axis inclined in its true position, on June 21. The Northern Hemisphere is tilted toward the sun; the Southern Hemisphere is tilted away from the sun. As the earth rotates for 24 hours on its tilted axis, all Northern Hemisphere points are in daylight longer than in darkness, while all Southern Hemisphere points are in darkness longer than in daylight. The closer a point is to the North Pole the more daylight it has; the closer it is to the South Pole the more darkness it has.

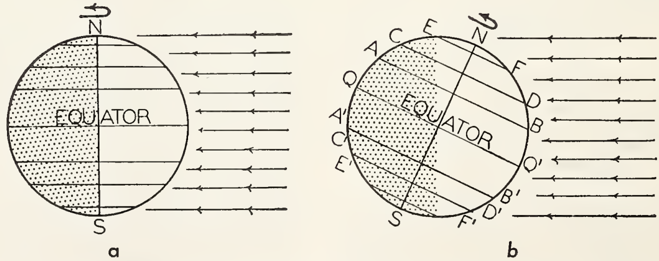


Fig. 20–8. (*a*) The earth, if its axis were vertical. (*b*) The earth with its axis inclined, as it appears on June 21.

The North Pole stays in daylight all 24 hours; the South Pole is in darkness for the full 24 hours. (The lines *AB*, *CD*, and *EF* are called *parallels* because they are parallel to the Equator.) On parallel *CD* it will take 24 hours for point *C* to rotate to *D*, and back again to *C*. The relative amounts of parallel *CD* in light and shadow give us the proportion of daylight and darkness for all places on *CD* in one day. If one-third of *CD* is in shadow and two-thirds are in sunlight, we know that *CD* has 8 hours of darkness and 16 hours of daylight on June 21. Similarly, the length of day and night can be worked out for any part of the world. Notice, however, that inclination makes no difference at all at the Equator, where there are always 12 hours each of day and night.

11. Parallelism of the earth's axis. Throughout its revolution in its orbit the earth's axis points in the same direction in space—toward the North Star. This behavior is called *parallelism*, because each position of the axis is parallel to every other position of the axis in the orbit. (Inclination at the same angle all the time does not necessarily include parallelism. Figure 20–9*a* shows how the earth might look on January 1 and July 1 if its axis did not always point toward the North Star. Figure 20–9*b* shows how the earth actually behaves. In both cases the inclination of the axis remains 23½ degrees.)

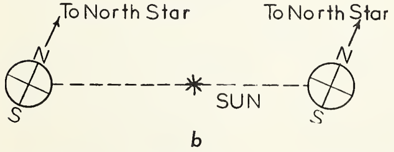


Fig. 20–9. (*a*) This shows how the earth might appear if its axis were inclined 23½° but did not stay parallel to itself. (*b*) This shows how the earth actually appears in its orbit. Its inclination of 23½° is always combined with parallelism.

12. Why day and night change in length. We now know that day and night alternate because of the earth's rotation, and that they are unequal everywhere, except at the Equator, because of the inclination of the axis. But why do day and night change in length from day to day? The answer is simple.

If the earth stayed in one place in its orbit, day and night would not change in length. The earth's constant revolution causes slight changes every day in the position of each hemisphere with respect to the sun, and these changes are steady and regular because of the parallelism of the earth's axis. Because of parallelism one hemisphere leans toward the sun at one end of the orbit, while six months later the other hemisphere leans toward the sun. See Figure 20–9*b*. Each hemisphere has its longest day when it leans the full 23½ degrees toward the sun; each has its shortest day when it leans the full 23½ degrees away from the sun.

In the six months between the longest and the shortest day, the days are constantly becoming either shorter or longer. In the Northern Hemisphere, June 21 is the longest day and December 21 the shortest day; in the Southern Hemisphere, June 21 is the shortest day and December 21 the longest. About halfway between these dates—on March 21 and September 23—day and night are equal in length throughout the world. March 21 is known as the *spring equi-*

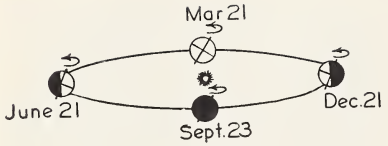


Fig. 20–10. How revolution and parallelism change the length of day and night. In June, the Northern Hemisphere is inclined to the sun, so it has long days and short nights. In December the Southern Hemisphere receives more sunlight. In March and September neither hemisphere is inclined toward the sun, so day and night are approximately equal for all the earth.

nox; September 23 is the *fall equinox* (*equi,* equal; *nox,* night).

Figure 20–10 illustrates the positions of the earth in its orbit on these four dates. On June 21 the earth's position is such that the Northern Hemisphere leans toward the sun the full 23½ degrees of the axis' inclination. At the same time, of course, the Southern Hemisphere is tilted an equal number of degrees away from the sun. The result is the longest day of the year for the Northern Hemisphere and the shortest day of the year for the Southern Hemisphere. On December 21 the positions are reversed.

On September 23 and on March 21 neither hemisphere is tilted in the direction of the sun. Day and night are therefore of equal length for the whole world. The change in "leaning" toward or away from the sun takes place gradually, a little each day, as the earth revolves. With each day's change in leaning toward the sun there comes a corresponding change in the length of day and night. *Day and night change regularly in length because of the earth's inclination, revolution, and parallelism.*

UNDERSTANDING THE SEASONS

13. Zenith, horizon, and sun. In discussing the position of the sun in the sky, it is helpful to use the terms *zenith* and *horizon.* To an observer standing out in the open, the sky looks like a great dome that is highest directly above him and comes down to meet the earth in a circle of which he is the center. The point in the sky that is directly above the observer is called the *zenith;* the circle where earth and sky seem to meet is the *horizon.* When the sun is rising or setting, it is on the horizon, and its rays just graze the earth, making an angle of

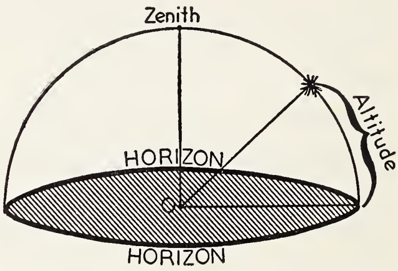


Fig. 20–11. Zenith, horizon, and altitude.

zero degrees with its surface. At noon—halfway between sunrise and sunset—the sun reaches its highest point in the sky for that particular day. If the sun is in the zenith, its rays make an angle of 90 degrees with the earth's level surface, and the sun's rays are said to be *vertical.* When the sun is near the zenith, its rays are *nearly vertical;* when it is far from the zenith, its rays are *slanting.* Vertical and nearly vertical rays have a much greater heating effect than slanting rays. Vertical rays are "strong"; slanting rays are "weak."

The height of the sun (or of any heavenly body) above the horizon, given in degrees, is called its *altitude.* Thus, when the sun is in the zenith, its altitude

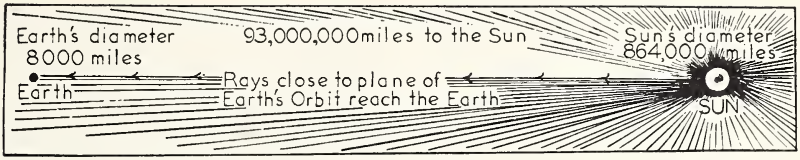


Fig. 20–12. Why the rays of the sun that reach the earth are parallel rays.

is 90°; when it is on the horizon, its altitude is 0°; when it is halfway from horizon to zenith, its altitude is 45°.

14. The sun's parallel rays. In the usual cartoonist's sketch, the sun is shown sending its rays into space in all directions. This is correct. However, at the vast distance of 93,000,000 miles the rays received by the comparatively tiny earth are practically parallel to each other and to the plane of the earth's orbit, as shown in Figure 20–12.

15. The sun's rays on the earth's surface. The sun's rays are all parallel to each other, but the earth's surface is curved. As a result, the sun's rays strike different parts of the earth's surface at angles ranging from 90° to 0°. These are shown in Figure 20–13, which is a "front" or "equatorial" view of the earth (as distinguished from a "top" or "polar" view like that of Figure 20–7) on June 21.

At any moment there is only one point on the earth's surface at which the sun is exactly vertical. In this diagram (Figure 20–13) it is point *P*. The ray that strikes this point is called the *sun's vertical ray*, and it is always on the line that joins the center of the earth with the center of the sun. North and south of *P* the sun's rays are *nearly vertical* for a good distance, but as the earth's curvature increases, the rays become more and more *slanting*. Notice how on this date, June 21, far more than half of the Northern Hemisphere is in the sunlight and receiving most of the nearly vertical rays.

Line XY is really the front half of a circle that marks the day and night parts

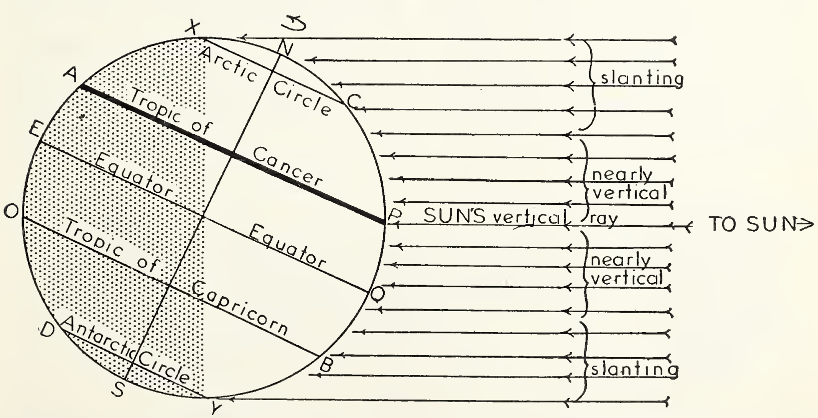


Fig. 20–13. The angles between the sun's parallel rays and the earth's curved surface on June 21.

of the earth. It is called the *twilight circle.* As the earth rotates from west to east around its axis *NS* every point on parallel *AP* will eventually have the sun's vertical ray strike it on this date. Point *P* and parallel *AP* are 23½ degrees north of the Equator *EQ*. *AP* is known as the Tropic of Cancer, and it marks the farthest north position of the sun's vertical ray on the earth. June 21 is known as the *summer solstice* (*sol,* sun; *stice,* stands) because the sun's vertical ray stands on the Tropic of Cancer before beginning a shift to the south. Six months later, when the earth is at the opposite end of its orbit, the sun's rays will come from the left (see Figure 20–14) and the vertical ray will be on the Tropic of Capricorn, 23½ degrees south of the Equator. This is known as the *winter solstice,* for at this time the vertical ray of the sun stops shifting southward and begins its northward return.

As the earth revolves around the sun the position of the sun's vertical ray changes constantly, covering all parts of the world between the Tropic of Cancer and the Tropic of Capricorn every 6 months. Between June 21 and December 21 the vertical ray "migrates" from Cancer to Capricorn, *passing the Equator on September 23.* Then from December 21 to June 21 the vertical ray "migrates" from Capricorn to Cancer, *passing the Equator again on March 21.* The area between the Tropics of Cancer and Capricorn is 47 degrees wide and is known as the *Torrid Zone.*

16. The solstices and the seasons. For at least a month before and a month after June 21, sunlight conditions are close to those on June 21, the date of the "beginning of summer." In what way do these conditions give the Northern Hemisphere its summer and the Southern Hemisphere its winter?

Basically there are two reasons why a day in June is warmer than a day in December in the Northern Hemisphere: (1) In June the *sun's rays are stronger* because they are more nearly vertical; (2) in June the *sun shines longer* than it does in December. Since these conditions prevail for several months, our weather in June, July, and August is our warmest weather. Weak sun and short days prevail through December, January, and February, giving us our coldest weather of the year.

In the Southern Hemisphere conditions are exactly reversed. Weak sun and short days make June, July, and August the winter months, while strong sun and long days make December, January, and February their summertime.

17. Day and night at the solstices. On June 21, the longest day of the year in the Northern Hemisphere, the time from sunrise to sunset is at a maximum

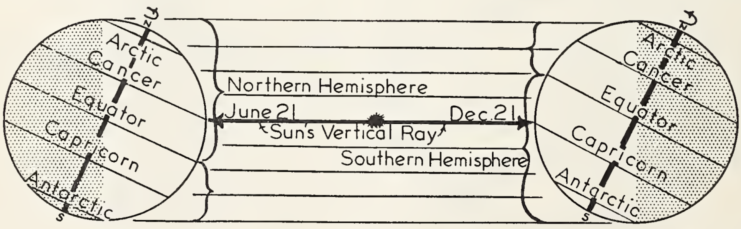


Fig. 20–14. The diagram shows that on June 21, date of the summer solstice, the Northern Hemisphere receives far more than half of all the sun's rays on the earth. On December 21, date of the winter solstice, Northern and Southern Hemisphere conditions are reversed.

for all places north of the Equator and at a minimum for all places south of the Equator. In the Northern Hemisphere the number of hours of daylight increases steadily the farther north we go from 12 at the Equator to 24 at the Arctic Circle (the parallel 23½ degrees from the North Pole). All of the earth north of the Arctic Circle has 24 hours of continuous daylight, and for much of this "frigid zone," daylight may continue for weeks or months. This is the "land of the midnight sun," which reaches its extreme in the North Pole's 6 months of daylight from March 21 to September 23. At the North Pole the sun goes round and round the sky, neither rising nor setting, but merely moving a little nearer or farther from the horizon from day to day.

In the Southern Hemisphere daylight decreases steadily from the Equator (12 hours) to the Antarctic Circle (0 hours). South of the Antarctic Circle there is no daylight on June 21, and the South Pole is in the midst of a night which lasts for 6 months from March 21 to September 23.

On December 21 days are shortest in the Northern Hemisphere and longest in the Southern Hemisphere. North of the Arctic Circle there is no daylight at all, and the North Pole is in the middle of its 6 months of night. South of the Antarctic Circle daylight is continuous for at least 24 hours, and the South Pole is in the middle of its 6 months of daylight.

In Canada the longest day of the year varies from 24 hours at the Arctic Circle and northwards to Ellesmere Land, to about 15 hours of day and 9 hours of night in southern Ontario on June 21; on December 21 conditions are exactly reversed, giving the southern cities 9 hours of day and 15 hours of night.

18. The equinoxes and the seasons. On or about March 21 and September 23, the sun's vertical ray is at the Equator and day and night are approximately equal in length throughout the world. Neither the Northern Hemisphere nor the Southern Hemisphere has any important advantages then in either strength of sunshine or length of daylight. However, on March 21 the Northern Hemisphere is beginning its spring, for its days are lengthening and its sunshine is becoming more vertical. In the Southern Hemisphere, March 21 is the beginning of fall. On September 23 the Northern Hemisphere begins its fall, and the Southern Hemisphere begins its spring.

19. Length of the seasons. If the earth did not revolve around the sun, there would be no seasons. Revolution determines the length of the seasons as well as the length of the year. On Mars, seasons are almost twice as long as on the earth, for Mars takes almost twice as long to revolve about the sun.

20. The sun at noon. In all parts of the world the sun reaches its highest position in the sky each day at noon, when it is midway between its rising and setting positions. Only in the tropics does it reach the zenith, and even there it is in the zenith on only two days of each year. In Canada and the United States the sun is never at the zenith because no part of these lands is as far south as the Tropic of Cancer.

In all parts of the United States the sun is highest in the sky on June 21 and lowest in the sky on December 21. In order for us to see the sun at noon in southern Canada, we must look somewhat to the south—more in winter, less in summer. (Refer to Figure 20–14; "look" toward the sun from any part of the earth north of the Tropic of Cancer.) That means that the sun at noon

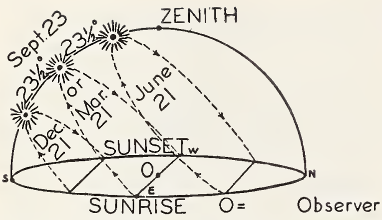


Fig. 20–15. The path of the sun in the sky at the latitude of Montreal, 45° N, on the dates of the equinoxes and the solstices. The total change in altitude from summer to winter is 47°.

is always directly south of the zenith for any observer in this country or for anyone else north of the Tropic of Cancer.

21. Summary: What causes the seasons. The causes of the seasons cannot be explained in a few words. The best that can be done briefly is to *state* the causes of seasons; the full explanation, as is evident from the preceding paragraphs, requires many more words. The three causes of the regular changes of seasons have been explained at length in this chapter. They are (1) the inclination of the earth's axis, (2) the parallelism of the earth's axis, and (3) the revolution of the earth about the sun.

22. The effect of distance. People studying the earth's orbit are always astonished to learn that "the earth is nearest the sun in winter and farthest away in summer." The common impression is that summer and winter are due to the changing distance of the earth from the sun. First of all, the statement in quotations is inaccurate. It is not the whole earth that has winter when nearest the sun, but merely the Northern Hemisphere. The Southern Hemisphere has its summer at that time. The Northern Hemisphere has its summer when it is farthest from the sun, but at the same time it is winter in the Southern Hemisphere. It is immediately obvious from this that changing distance from the sun is not the cause of the seasons; if it were, the whole earth would have the same season at the same time. For the true explanation of seasonal change we must look to other causes which have already been given.

Why is our changing distance from the sun so unimportant that we may have winter and summer with no regard to the distance? Once again the answer is a simple one. The difference between perihelion distance, where the earth's orbit is nearest the sun, and aphelion distance, where the orbit is farthest from the sun, is 3,000,000 miles. This seems like a great distance, but proportionately it is small, for it is only about 1/31 of the total distance between earth and sun. The situation is comparable to that in which a man is 31 feet from a campfire. If he felt cold, he could certainly make himself warmer by moving closer to the fire, but moving a distance of only one foot would make very little difference. So it is with the earth.

It is true, however, that the earth as a whole receives a little more heat from the sun in January than in July. If our orbit were very eccentric, like Pluto's, then change in perihelion and aphelion distance would have a tremendous seasonal effect.

HAVE YOU LEARNED THESE?

Meanings of: orbit, plane of the orbit, revolution, rotation, axis, equator, perihelion, aphelion, oblate spheroid, equinoxes, solstices, zenith, horizon, altitude of the sun, Tropic of Cancer, Tropic of Capricorn, Arctic Circle, Antarctic Circle

Diagrams of: the earth's elliptical orbit; north polar view of the earth; the solstices and the seasons

Explanations of: the inclination of the earth's axis; the effect of rotation on the earth's shape; why day and night exist, alternate, are unequal, and change in length; why seasons change; why Northern and Southern hemispheres have opposite seasons; day and night on the equinoxes and solstices; rate of rotation and revolution

Relations between: distance from the Equator and variations in length of day and night; seasons and distance from the sun; revolution and length of seasons; seasons and the solstices; seasons and the equinoxes; seasons and the position of the noon sun in the sky

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. In what four respects does the earth have advantages over other members of the solar system in "living conditions"?

2. State four points of evidence of the fact that the earth is a sphere.

3. (*a*) What is meant by the earth's orbit? its revolution? the plane of its orbit? (*b*) State the direction and rate of the earth's revolution.

4. (*a*) Why does the distance between the earth and the sun keep changing all year? (*b*) Define perihelion and aphelion, giving dates and distances.

5. (*a*) What is rotation? What is an axis? (*b*) Describe the earth's rotation and its axis. (*c*) Explain the inclination of the earth's axis. (*d*) What is the Equator?

6. (*a*) At what rate does the earth rotate in degrees? in miles per hour? Explain. (*b*) Why is the earth said to rotate counterclockwise? From what position of the observer would it rotate clockwise?

7. Explain why the earth is an oblate spheroid and give its dimensions.

8. (*a*) What are the four problems involved in explaining day and night? (*b*) What causes day and night?

9. Referring to Figure 20–7, explain why day and night alternate.

10. Explain why day and night are not equal in length and how they vary in length from the Equator to the poles. Refer to Figure 20–8.

11. With the aid of a diagram, explain what is meant by the parallelism of the earth's axis.

12. (*a*) Explain why day and night change in length from day to day. (*b*) Why are day and night equal in length on the equinoxes? (*c*) Why are June 21 and December 21 the longest and shortest days of the year in the Northern Hemisphere? (*d*) What relation is there between the length of day in the Northern Hemisphere and the length of day in the Southern Hemisphere?

13. With the aid of diagrams, explain the meaning of: zenith, horizon, altitude, vertical rays, slanting rays.

14. Why does the earth receive parallel rays from the sun?

15. (*a*) Why do the sun's rays strike the earth's surface at various angles? (*b*) What is the "sun's vertical ray"? (*c*) What is the twilight circle? (*d*) What are the Tropics of Cancer and Capricorn? (*e*) What are the solstices? (*f*) Describe the "migration" of the sun's vertical ray.

16. (*a*) Why is the Northern Hemisphere warmer in June than in December? (*b*) Why is the Southern Hemisphere warmer in December than in June?

17. (*a*) Describe the distribution of day and night throughout both hemispheres on June 21 and December 21. (*b*) How much daylight does the United States have on June 21 and December 21?

18. (*a*) Why are both hemispheres about equally heated by the sun at the equinoxes? (*b*) What seasons begin at these times?

19. What determines the length of the seasons?

20. Why is the sun always below the zenith and always to the south in Canada at noontime?

21. State the three causes of the regular change of seasons.

22. (*a*) What evidence is there that our seasons are not caused by changing distance from the sun? (*b*) Why is a change in distance of 3,000,000 miles so unimportant for us?

GENERAL QUESTIONS

1. What other conditions, besides those listed in Topic 1, make the earth better fitted for life than the other planets?

2. How may the weight of an object be used to show the oblate shape of the earth?

3. Suppose the earth's North Pole always pointed toward the sun (as in Figure 20–9*a*). What would happen to seasons?

4. Compare the length of day and night in New York City with that in Mexico City, Montreal, and Buenos Aires on June 21 and December 21.

5. Where would the noon sun be in the sky at the Equator on the two equinoxes and the two solstices?

6. How would increased inclination of the earth's axis change: (*a*) the length of day and night? (*b*) the seasons?

7. How would decreased inclination of the axis affect seasons and the length of day and night?

8. Suppose the earth rotated from east to west at twice its present rate. What changes would be made in our day?

9. Suppose the earth revolved at twice its present speed. How would seasons be affected?

STUDENT ACTIVITIES

1. Observing the direction of the sun at sunrise, noon, and sunset
2. Observing the change in the sun's altitude from day to day
3. Plotting the times of local sunrise and sunset and the length of day throughout the year
4. Plotting the variation in the length of day throughout the world on the solstices and equinoxes
5. Drawing the earth's orbit to scale
6. Drawing the earth to scale
7. Making models to show day and night, solstices, and equinoxes
8. Making a model of the earth's orbit

SUPPLEMENTARY TOPICS

1. Foucault's Proof of the Earth's Rotation
2. Eratosthenes' Measurement of the Earth's Circumference
3. Proofs of the Earth's Revolution
4. Kepler's Laws of Planetary Motion
5. The Ellipse
6. Precession of the Axis
7. The Direction of Sunrise and Sunset
8. The Midnight Sun
9. Polar Night

See list of suggestions for further reading at end of Chapter 17.

Chapter 21

LOCATION AND NAVIGATION

1. Going places. In our daily lives we are always "going places." We go to school, to the store, to the movies, to the homes of friends. In vacation times we may go on longer trips, perhaps to a neighboring state, or even across the country. These trips present few "navigation" problems. We ride in trains that follow steel tracks, or in automobiles that follow marked highways. We walk on labeled streets, and hike on marked trails in the woods. All we need be sure of is to take the "right" train, the "right" highway, or the "right" trail, and then watch the signposts.

"Going places" is done in much the same way by the pilot of a river steamer, a coastwise vessel, or the short-hop airplane, for they too may follow the "roads" and watch the landmarks. But for the pilot of a transoceanic ship or airplane the problems of navigation are different. In midocean there are no streets, no marked highways, no signposts, and no landmarks. The pilot who wishes to find his way to his destination must know how to "get his bearings"—he must be able to determine his location on the earth's surface and guide himself in the proper direction. In short, he must be able to find his latitude and longitude, and locate north, south, east, and west.

2. Location schemes. A stranger in a big city does have his navigation problems if the city fathers gave little thought to the arrangement of streets and avenues in planning their city. The simplest arrangement is usually one in which streets and avenues are laid out in north-south and east-west directions, spaced equally, and numbered consecutively. Such a scheme has been created for the entire surface of the earth, so that ship and plane pilots may determine their exact locations on the oceans or in the air, and geographers may define exact boundaries between states and countries. The north-south "streets" of the earth are called *meridians;* the east-west "streets" are called *parallels.* These "streets" have no signposts and are not paved, so special methods must be devised to identify them. We often speak of them as imaginary lines, but on maps and charts they are as real as highways, and the trained navigator has no difficulty in finding and using them.

3. Latitude and degrees. Our system of latitude and longitude makes use of the earth's North and South Poles as reference points. To divide the earth into a Northern Hemisphere and a Southern Hemisphere the Equator is drawn as a circle running around the

earth exactly halfway between the Poles. We are now ready to define latitude. *Latitude is the distance in degrees north or south of the Equator.* To measure latitude, equal distances from the Equator are marked off by *parallels* which are imaginary *circles that go around the earth parallel to the Equator.* Like the Equator, they run in an east-west direction. As shown in Figures 21–1 and 21–2 the closer a parallel is to the North or South Pole the smaller it is.

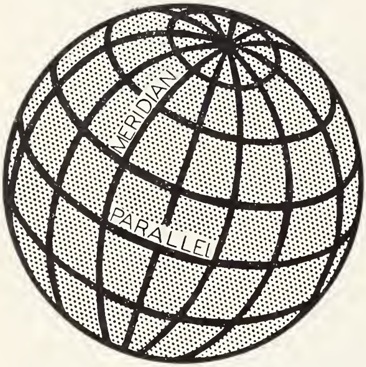


Fig. 21–1. Parallels and meridians in a tilted view of the earth.

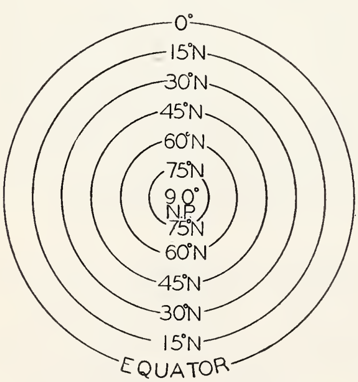


Fig. 21–2. Parallels as seen in a polar or top view of the earth.

Latitude is expressed in degrees, not in miles. Since the Equator is the starting place from which latitude is measured, it is numbered 0°. Places north of the Equator have *north latitude;* places south of the Equator have *south latitude.* The two Poles are the points most distant from the Equator; the North Pole's latitude is 90° N and the South Pole's latitude is 90° S. (From the Equator to either pole is one-fourth of the distance around the earth. One-fourth of 360 degrees is 90 degrees.) Each parallel is named only by its distance from the Equator, except for the Tropics of Cancer and Capricorn (23½° N and 23½° S) and the Arctic and Antarctic Circles (66½° N and 66½° S). Canada lies approximately between the 42° N and 83° N parallels.

4. Latitude and miles. It is easy to calculate the number of miles in a degree of latitude. The total distance around the earth through the poles is 24,890 miles. Divided by 360, this gives an average of about 69 miles to a degree of latitude. Since the earth is not perfectly round, there is a slight variation in the length of a degree of latitude all the way from the Equator to the Poles. At the Poles, where the earth is flattest, a degree of latitude is almost a mile longer than at the Equator. (For approximate calculations we usually use 70 miles to one degree of latitude.)

Degrees alone are too large for precise locations on the earth, so they are subdivided into *minutes* and *seconds.* A degree includes 60 minutes (written as 60′); each minute includes 60 seconds (written as 60″). To find the length of 1 minute (1′), we divide 70 miles (in 1°) by 60. A *minute* is therefore equal to 1 1/6 miles—about 6000 feet. To find the approximate length of 1 second (1″), we divide 6000 feet by 60. A

second is therefore equal to about 100 feet.

A minute of latitude is the same as 1 *nautical mile*, which is therefore the equivalent of 1 1/6 ordinary (statute or legal) miles.

5. Longitude and degrees. At right angles to the parallels are the *meridians*, the north-south streets of the earth. All meridians extend from the North Pole to the South Pole, and each meridian is therefore a semicircle covering half of the earth's circumference. See Figure 21–3. Distance between meridians is

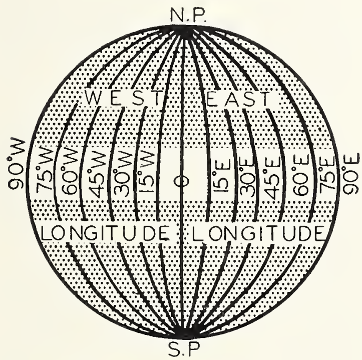


Fig. 21–3. Whole meridians reach from pole to pole, as seen in an equatorial or front view of the earth.

known as *longitude*. As with latitude, these distances are measured in degrees, minutes, and seconds of the earth's curved surface. There is no "natural" midpoint like the Equator from which longitude can be measured, but most countries have agreed to use the meridian that runs through Greenwich (near London), England, for this purpose. This meridian is called the *prime meridian* (first meridian) and is numbered 0°. *Longitude is the distance in degrees east or west of the prime meridian.* The half of the earth that lies east of the prime meridian has *east longitude* up to 180° (half of 360°); the half that lies west of the prime meridian has *west longitude* up to 180°. The 180th meridian is the same one for both east and west longitudes; it is directly opposite the Prime Meridian on the earth's surface, as shown in Figure 21–4.

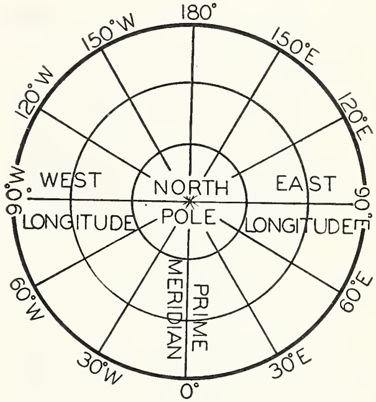


Fig. 21–4. Half-meridians from the North Pole to the Equator, as seen in a polar or top view of the earth.

The North Pole and South Pole have no longitude since all the meridians meet there. North and South America are entirely in west longitude, while most of Europe, Africa, Asia, and Australia are in east longitude. Canada lies approximately between the 53° W and 141° W meridians.

6. Longitude and miles. The distance between a pair of parallels is the same in all parts of the earth, for parallels really are parallel to each other. But meridians are not parallel to each other. On the contrary, all the meridians converge (draw closer to each other) as they approach the Poles, where they finally meet. See Figures 21–3 and 21–4. Because of this convergence there is no single value in miles for a degree of lon-

gitude. At the Equator a degree of longitude is just about as long as a degree of latitude, that is, about 70 miles. In higher latitudes (nearer the poles) the length of a degree of longitude steadily decreases, until at the Poles it is zero. At 40° latitude a degree of longitude equals about 53 miles.

7. Location by latitude and longitude. In geometry it is said that two straight lines can intersect in only one point. The same thing is true on the face of the earth for a particular parallel and meridian. When we give the latitude and longitude of the center of Regina, Saskatchewan as 50° 27′ N and 104° 37′ W, we are saying that it lies at the intersection of those two lines on the earth's surface. Similarly, we may locate Quebec City approximately at 47° N and 71° W; St. John at 45° N and 66° W; Boston at 42° N and 71° W; London at 51° N and 0°; Paris at 49° N and 2° E; Buenos Aires, Argentina, at 35° S and 59° W; and Hong Kong, China, at 21° N and 114° E.

8. Navigation. In the absence of landmarks the navigator attempting to guide his ship or plane to its destination has two main problems. In order to go in the right direction he must be able to determine the "points of the compass." In order to plot his course correctly he must be able to determine his ship's position (latitude and longitude) from time to time. Determination of a ship's position by observations of the sun, moon, planets, or stars is known as *celestial navigation.*

9. Finding north. As a rule, directions are determined by finding north. If one faces north, south is to the rear, east is to the right, and west is to the left. Several different methods may be used to find north.

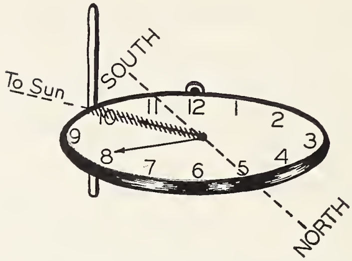


Fig. 21–5. Finding north by using a watch. In order to make certain that the hour hand is pointing directly at the sun, a small stick is held vertically at the end of the hour hand, and the watch is turned until the stick's shadow is exactly in line with the hour hand. South is then halfway between the hour hand and 12, and north is just opposite south.

(1) At night, north is given almost exactly by the position of Polaris, the North Star, easily found by following the pointer stars of the Big Dipper (see Figure 17–7).

(2) In the daytime, north may be found by observing the sun at apparent noon, when it crosses the meridian or north-south line in the sky. At that moment, the shadow of any vertical post will run true north and south. Apparent noon can be identified by the fact that shadows are shortest at that time, since

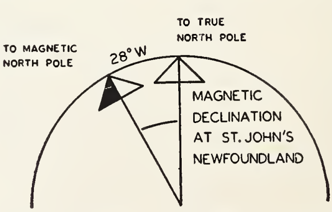


Fig. 21–6. Using a compass to find true north. The compass needle points to the magnetic north, and correction must be made for the magnetic declination of the locality. In St. John's, Newfoundland, the declination is about 28° west.

the sun is at its highest point in the sky for that particular day. (Approximate north may be found at any time of day by pointing the hour hand of a watch directly at the sun. The point halfway between the hour hand and 12 o'clock is south; directly opposite is north. See Figure 21–5.)

(3) The magnetic compass gives *magnetic north.* From this, true north can be obtained by making the proper correction for *magnetic declination. Magnetic declination is the angle by which the compass needle varies from true north,* and it is caused by the fact that the north magnetic pole of the earth, toward which the compass points, is not at the earth's North Pole. The navigator carries charts which tell him the magnetic declination for all parts of the earth (Figure 21–6).

10. Determining latitude. Finding latitude by observation is based on the principle that at different latitudes the stars and the sun will appear at different altitudes in the sky. By simple geometry it can be shown that for any point in the Northern Hemisphere, *the altitude of the North Star is equal to the latitude of the observer.* For example, at the North Pole, latitude 90° N, the North Star is in the zenith, and its observed altitude is 90°. At Vancouver, latitude 49° N, the North Star's altitude is 49°. If the captain of a ship observes the

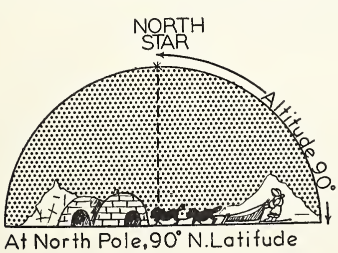


Fig. 21–7. The North Star's position in the sky at the North Pole.

North Star at an altitude of 41°, he knows that he is in latitude 41° N. The instrument used to observe and measure the altitude of stars, planets, and the sun is the *sextant* or *octant.*

Latitude may be determined in the daytime from the sun's noon position in the sky. Either the sextant or octant is used to "shoot the sun"—that is, to measure its altitude; the *Nautical Al-*

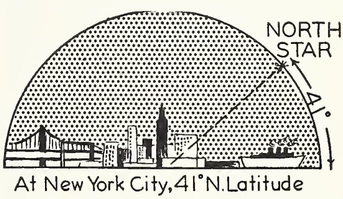


Fig. 21–8. The North Star's position in the sky at 41° N, the latitude of New York City.

manac or *Air Almanac* is then consulted to find out in what latitude the sun has the observed altitude on the day of the observation.

11. Determining longitude. The determination of longitude—distance east or west of the prime meridian—is based

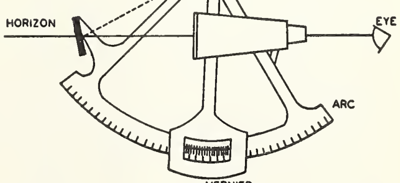


Fig. 21–9. The sextant. The observer moves his arm so that the sun and the horizon are both seen in the telescope, then reads the altitude from the scale.

on the principle that differences in time exist between the prime meridian and places east or west of it. These differences are equal to one hour for every 15 degrees of longitude. Since the sun rises in the east, places east of the prime meridian have later time, while places west of the prime meridian have earlier time. If the ship's observer can determine the difference in time between his location and Greenwich, he can calculate his longitude. For example, if sun time at his location (local time) is 2 hours earlier than Greenwich time, his ship is at 30° W longitude.

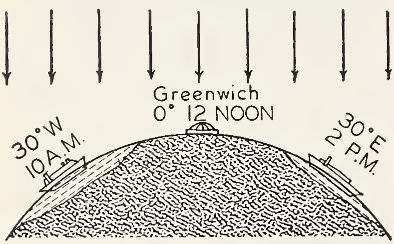


Fig. 21–10. How longitude is related to clock time. For each 15° longitude eastward, time is 1 hour later.

Greenwich time is obtained simply by carrying on the ship a very accurate clock, called a *chronometer*, which is set at Greenwich time and kept running that way, just as anyone may keep one of the clocks in his house at London time, Tokyo time, or any other time. Greenwich time signals are also transmitted over government radio stations at regular intervals. Local time is obtained most accurately at noon, when the sun crosses the meridian, as explained in Topic 9. In other words, the practice is to read the chronometer at local noon, and then calculate the longitude. For example, if the ship's chronometer says 8 A.M. at local noon, it means that the ship's time is 4 hours later than Greenwich time, and the ship is therefore at 60° E longitude. The chronometer is a 24-hour clock, otherwise it would be impossible to know whether the time was A.M. or P.M. at Greenwich.

12. Celestial navigation methods. At night, in actual practice, a navigator usually determines his ship's position by nearly simultaneous sextant observations of any two bright stars or planets listed in the *Nautical* and *Air* almanacs. Each observation enables him to plot a line of position on a chart of the earth, and the point at which the two lines of position intersect is the ship's position, or *fix*. Sirius, Rigel, Arcturus, and Capella are but a few of the bright stars listed in the almanacs.

In the daytime, the ship's position is usually determined at local noon, when the sun's altitude is used in calculating the latitude and the reading of the chronometer is used in calculating the longitude, as explained in Topics 10 and 11.

13. Dead Reckoning. If the navigator knows the approximate direction and speed at which he has been traveling, he can figure out his position on his charts. Deducing the position of a ship in this way is known as *dead reckoning*.

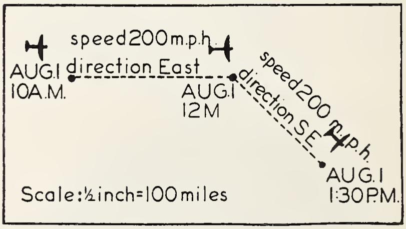


Fig. 21–11. Plotting position by dead reckoning. If the navigator knows his speed, his direction, and the time he has been traveling, he can find his approximate position on a map.

The reckoning can be brought up to date as often as desired. Positions determined by dead reckoning are not entirely accurate, but they are valuable in cloudy weather and between the times of celestial observations.

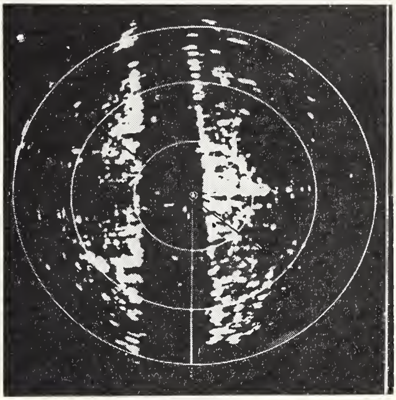
The speed of a ship is measured in *knots. A knot is one nautical mile per hour.* The ship's *log* is the instrument that shows the speed of the ship.

14. Air navigation. Air-navigation methods may be classified under four headings. In fair weather over familiar land areas, the air navigator may follow landmarks such as highways, power lines, rivers, and mountain peaks as he navigates by *pilotage,* also known as *contact flying.* In fair weather over the oceans or land, he may fly by *celestial navigation.* When clouds hide the ground or the sky, or both, the navigator directs his courses by *dead reckoning* or by *radio navigation,* also known as *instrument flying.*

Celestial navigation and dead reckoning have already been described. In radio navigation the airplane is guided by *radio beams* and *radio beacons,* and the airplane's position can be determined by making a fix on two radio transmitting stations, in much the same way as a fix is made on two stars in celestial navigation.

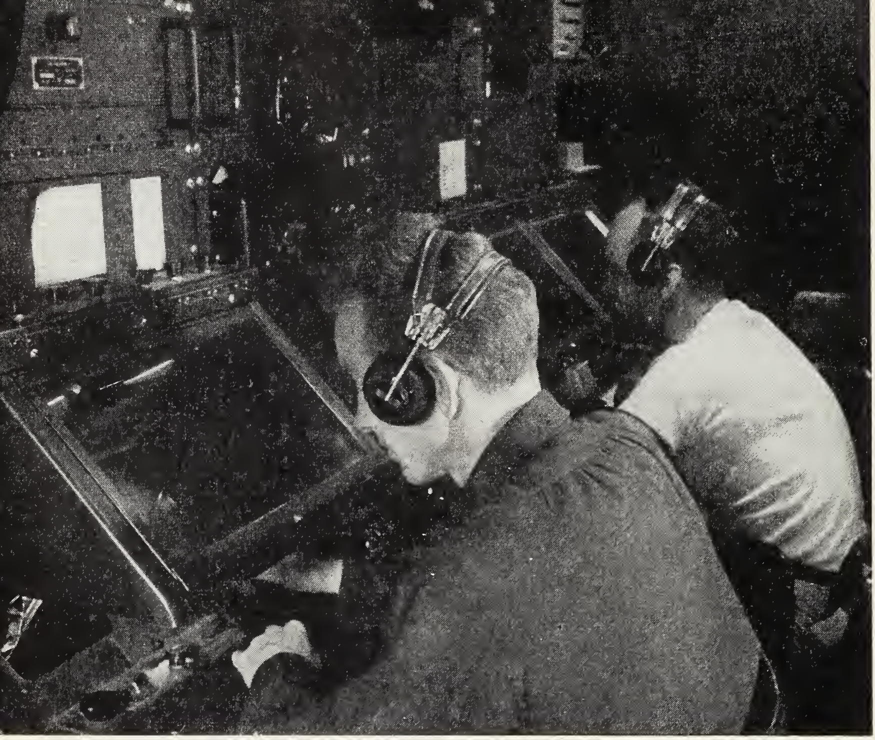
15. Radar in navigation. In foggy weather, ships may use *radar* equipment to detect the presence of nearby ships, icebergs, sand bars, or reefs, and thus avoid collision. The radar transmitter sends out a signal, or "beam," which is reflected from solid objects back to the ship. The reflected signal, picked up by a receiver, lights a screen that resembles a television screen. The position of the light on the screen indicates the size, direction, and distance of the reflecting object.

Airplanes may also use radar in navigating when visibility is poor. Radar is now used "in reverse" in helping airplanes to make airport landings in bad weather. The control tower at the airport sends out a beam of radar waves. The beam strikes the incoming airplane and is reflected back to a receiver in the control room. From the position of the plane's image on the receiver screen the control operator can tell just where the plane is. Talking to the pilot by two-way radio telephone, the operator gives the pilot landing instructions. This procedure is technically called GCA, meaning "ground control of approach." It is also known as "talking the plane down."



Radiomarine Corporation of America, A Service of RCA

Fig. 21–12. Appearance of the screen or radarscope on a Radiomarine radar set aboard a ship whose position in the Hudson River (black) near Manhattan (white) is shown by the tiny white dot at the exact center of the screen. To the right of the ship is Manhattan, to the left is New Jersey (white). The straight line shows the heading of the ship—south towards the Narrows and the Atlantic Ocean. The large circles represent fixed distances from the ship.



National Film Board, Canada

Fig. 21–13. The tracker and controller at the controls of Ground Control Approach, Gander Airport, Newfoundland. The controller uses voice radio to give the pilot landing directions.

16. Great-circle routes. Circles drawn on the surface of a sphere may be either *great circles* or *small circles*. A *great circle is a circle whose plane passes through the center of the sphere*. Perhaps it is simpler to say that any circle that divides the sphere in half is a great circle. All other eircles drawn on the sphere are smaller than the great circles and are called *small circles*. On the earth the Equator is a great circle, but all the parallels are small circles. Each meridian is half of a great circle; the meridian opposite it in the other hemisphere is the other half. Great circles may also be drawn in oblique positions between the Equator and the Poles, just as an orange may be cut in half in any direction.

The importance of a great circle in navigation is due to the fact that *a great-circle route is the shortest distance between two points on a sphere*, just as a straight line is the shortest distance be-

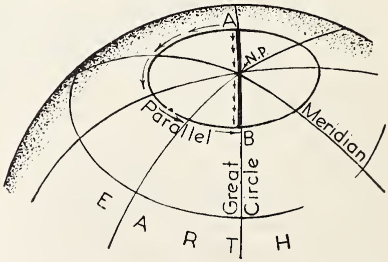


Fig. 21–14. The *great circle* route from A to *B* is much shorter than the route along the parallel, a *small circle*.

tween two points on a plane. On a sphere, a small circle is as indirect a route as a curved line would be on a plane.

Figure 21–14 shows a great-circle route between two points, *A* and *B*, that are on the same small-circle parallel. Great-circle routes are the shortest routes but not always the most desirable, since winds, ocean currents, icebergs, and many other factors must also be taken into account. Airplanes are more likely than ships to be able to make use of great-circle routes. Great-circle routes between cities in high latitudes pass over or near the Poles, which is why we hear so much about over-the-pole routes for airplanes.

HAVE YOU LEARNED THESE?

Meanings of: latitude, longitude, parallels, meridians, prime meridian, sextant, chronometer, local noon, knot, great circle, nautical mile

Explanations of: the earth's location scheme; the variations in the length of latitude and longitude degrees; finding north; finding latitude; finding longitude; dead reckoning; celestial navigation; great-circle routes; determining apparent noon; methods of air navigation; use of radar in navigation

Expression of: latitude in degrees; longitude in degrees; degrees in miles

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. In what ways are the navigation problems of the transatlantic ship or plane different from those of the railroad engineer, the bus driver, the hiker, the riverboat captain, and the short-hop pilot?

2. Describe a simple street scheme for a city, and explain briefly how the scheme for the earth follows this idea. Why is a location system for the earth necessary?

3. (*a*) Explain how the latitude system of the earth is set up. (*b*) Define latitude, Equator, parallels. (*c*) Explain and give examples of the manner in which latitude is expressed.

4. (*a*) How long is each of the following: (1) a degree of latitude; (2) a minute of latitude; (3) a second of latitude? (*b*) Explain why and how degrees of latitude vary in length over the earth.

5. (*a*) Explain how the longitude system of the earth is set up. (*b*) Define longitude. (*c*) Explain the relation between meridians and the prime meridian. (*d*) Explain the division of the world into longitude degrees, and give examples.

6. Explain why no single value can be given for the number of miles in a degree of longitude.

7. (*a*) How do the latitude and longitude of a place indicate its exact location? (*b*) Give the latitude and longitude (degrees only) of three big cities.

8. (*a*) What are the two main problems of the navigator working without landmarks? (*b*) What is celestial navigation?

9. (*a*) Explain how to find north using: (1) Polaris; (2) the sun; (3) the magnetic compass. (*b*) What is meant by apparent noon, and how can the instant of apparent noon be identified?

10. (*a*) Explain how the North Star is used to determine latitude. (*b*) How is the sun used in determining latitude? (*c*) What are the sextant and octant?

11. (*a*) How is longitude determined? Give examples. (*b*) What is a chronometer? (*c*) Why is longitude on a ship usually determined at local noon?

12. (*a*) Explain the celestial-navigation method used to get a fix at night. (*b*) How is the ship's position usually determined in the daytime?

13. (*a*) Describe dead reckoning and explain its uses. (*b*) What is a knot? ship's log?

14. Briefly describe the four methods of air navigation.

15. What use is made of radar in navigation? What is GCA? Explain.

16. (*a*) What are great circles? Give some examples. (*b*) Why are great circles important in navigation?

GENERAL QUESTIONS

1. Approximately how many miles is it to the Equator and to the North Pole from each of the following cities: New York, London, Buenos Aires, Hong Kong?

2. Explain why the rule for finding north by the use of a watch should be true.

3. At local noon on board a ship on June 21, the sun is in the zenith and the chronometer time is 3 P.M. What are the ship's latitude and longitude?

4. What is the altitude of the North Star at each of the cities listed in Topic 7?

5. In Topic 15 it is stated that airplanes are more likely than ships to be able to make use of great-circle routes. Why?

6. In Topic 13 it is stated that positions obtained by dead reckoning are not entirely accurate. Why?

7. By dead-reckoning methods, using a scale of 1 inch to 200 miles, show the position of a plane that has been flying northwest at 200 miles per hour for 2 hours after leaving its starting point, and then goes due west at 250 miles an hour for 2 hours. Assume any starting point on your map.

STUDENT ACTIVITIES

1. Plotting locations on maps from latitude and longitude
2. Reading latitude and longitude from maps
3. Marking great-circle routes on globes
4. Calculating the "savings" in great-circle routes
5. Finding north by the sun-watch method
6. Determining: (1) the time of apparent noon; (2) true north, by the shortest-shadow method
7. Using the sextant
8. Finding north with the magnetic compass
9. Determining the local longitude from Greenwich time at apparent noon
10. Using Polaris to find north and to determine latitude

SUPPLEMENTARY TOPICS

1. Using the Sun to Find Latitude
2. The Variations of Polaris from True North
3. Magnetic Declination
4. The Use of the Sextant and the Octant
5. The Mathematics of the Sextant
6. The Chronometer
7. The Fix in Celestial Navigation
8. The Origin of the Knot
9. Measuring a Ship's Speed
10. Radio Navigation
11. Radar in Navigation
12. How Great-Circle Routes Are Followed
13. The Gnomonic Map Projection

SUGGESTIONS FOR FURTHER READING

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Elements of Aeronautics, by Pope and Otis. World Book, Yonkers, New York, 1941.

Principles of Air Navigation, by B. Shields. McGraw-Hill, New York, 1943.

Air Navigation, by P. V. H. Weems. McGraw-Hill, New York, 1943.

Practical Air Navigation (*C.A.B. Bulletin No. 24*). Superintendent of Documents, Washington 25, D.C.

American Air Almanac. Superintendent of Documents, Washington 25, D.C.

Encyclopaedia Britannica.

(*Also see list at the end of Chapter 17.*)

Chapter 22

KEEPING TIME

Introduction. The keeping of time on the earth is not a simple matter. Take just a few illustrations. News dispatches from Korea or the Philippine Islands tell us on Monday what is happening there on Tuesday! A solar eclipse begins on the earth on a Saturday and ends, hours later, on Friday! A boxing match is begun in Los Angeles at 7 P.M. so that television watchers in the East may see it at 10 P.M. How are these happenings explained?

1. Units of time. Because the earth moves at uniform speeds, we base our measurement of time on its motions. We define a *year* as the time taken by the earth to make one revolution around the sun. A *day* is the time taken by the earth to make one rotation on its axis. Saying that a year has 365¼ days (approximately) simply means that the earth rotates on its axis 365¼ times while it is making one revolution around the sun. (The month is not a natural unit of time, although it is close to the 29½ day period between new moons from which it originated.)

Since man requires shorter units of time than the day, he himself has divided the day into 24 equal parts called *hours.* Each hour is divided into 60 *minutes,* and each minute is divided into 60 *seconds* The hour, minute, and second represent man's own divisions of the natural unit of time given him by the earth's rotation.

2. Measuring a day. Astronomers define a *day as the interval of time in which a particular heavenly body crosses the observer's meridian* (a north-south line through the sky) *twice in succession.* It is in this way that we can tell when the earth has made exactly one rotation, just as a rider on a merry-go-round can count his rotations by noticing how often he passes a fixed object that is outside the merry-go-round. If the observer counts the time taken by a *star* to cross his meridian twice, he is measuring a (star) or *sidereal* (sy *deer* ee ul) *day.* If he counts the time taken for the *sun* to cross his meridian twice, he is measuring an *apparent solar day.* The moment at which the sun crosses the meridian each day is known as *apparent solar noon.*

3. Mean solar day. As pointed out in Chapter 20, the distance between the earth and the sun changes every day. One effect of this is to make the length of an apparent solar day vary slightly throughout the year, so that the time taken for the sun to come back to the meridian is almost a minute longer in October than in January. For purposes

of simpler time-keeping, all the apparent solar days of the year are averaged; the average is known as the *mean solar day*. It is this *mean* (average) solar day that is 24 hours long.

4. Mean solar time. When we use the mean solar day as our unit of time, counting exactly 24 hours each day from midnight to midnight, we are keeping *mean solar time* or *local civil time*. Twelve o'clock noon is then *mean solar noon*, the exact middle of the mean solar day. Except for four days of the year, *apparent solar noon does not come at twelve o'clock*. The difference between apparent solar noon and mean solar noon is called the *equation of time*. When the sun crosses the local meridian before twelve o'clock, the sun is said to be *fast*; when it crosses after twelve o'clock it is *slow*. The equation of time may be as much as 16 minutes.

A sundial shows apparent solar time, and the equation of time must be used to convert sundial time into local time. The equation of time can be found in most almanacs. Apparent solar noon can easily be calculated for any day merely by determining the exact midpoint between sunrise and sunset. For example, if on December 3 the sun rises in Philadelphia at 7:06 A.M. and sets at 4:33 P.M., it actually crosses the meridian at 11:49½ A.M., which is apparent solar noon.

5. Local pride and local time. Places that are on the same meridian have the same solar time because the sun crosses the entire meridian at the same instant. On the other hand, places that are even a short distance east or west of each other have different solar time, since the rotation of the earth from west to east brings the sun across each meridian at a different instant. The differences in solar time amount to 1 hour for every 15 degrees of longitude, or 4 minutes for each degree of longitude, or one minute for every ¼ degree of longitude. For example, Montreal's longitude is 73½° W; Toronto's 79½° W. Because of this difference of six degrees, the sun reaches the meridian at Montreal 24 minutes before it reaches the meridian at Toronto about 300 miles west. (See Figure 22–1.)

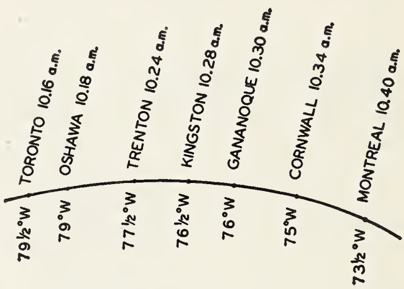


Fig. 22–1. If every city kept its own time by the sun.

Until 1883 most cities and other localities in North America kept their own solar time. Fifty-three different kinds of time were used by the country's railroads, and cities through which several railroads ran had as many as five different time systems. On November 18, 1883, American railroads adopted *standard time*, which is in world-wide use today.

6. Standard time. In standard time, meridians are marked off at intervals of 15 degrees east and west of the prime meridian at Greenwich, England. These 24 meridians—15° E, 15° W, 30° E, 30° W, and so on, up to 180°, are called *time meridians*. Each time meridian is the center of a *standard-time* zone that is 15 degrees wide—7½ degrees on each side. The entire zone has the same time; all clocks show the *mean solar time of the time meridian in that zone*. In the

zone to the east the time is exactly 1 hour later; in the zone to the west it is exactly 1 hour earlier. Thus changes of time are made only one hour at a time, and only when crossing from one zone into the next. To calculate the standard time in any part of the world, we merely add one hour for each 15-degree zone to the east, and subtract one hour for each 15-degree zone belt to the west. For example, when it is 10 A.M. at London, 0° longitude, it is 1 P.M. in Rome, 15° E, 5 A.M. in Philadelphia, 75° W, and so on. A rhyme that may aid in remembering this rule is:

> As you go to the east
> The time doth increase.
> As you go to the west
> The time will grow less.

7. Standard time belts (zones) in Canada. Theoretically each standard time zone is 15 degrees wide. On land, however, such exactness is undesirable and unnecessary. It is undesirable because exact boundaries might cut right through a city or between localities that wish to keep the same time. It is unnecessary as long as the irregular zones (or belts) *average* 15 degrees in width. Seven time meridians pass through Canada. Canada has therefore seven Standard time belts, all with irregular boundaries. The belts and their time meridians are: Newfoundland, 52½° W; Atlantic, 60° W; Eastern, 75° W; Central, 90° W; (Rocky) Mountain, 105° W; Pacific, 120° W; Yukon, 135° W; The Pacific Belt is 45° (or 3 belts) to the west of the Eastern Belt and is

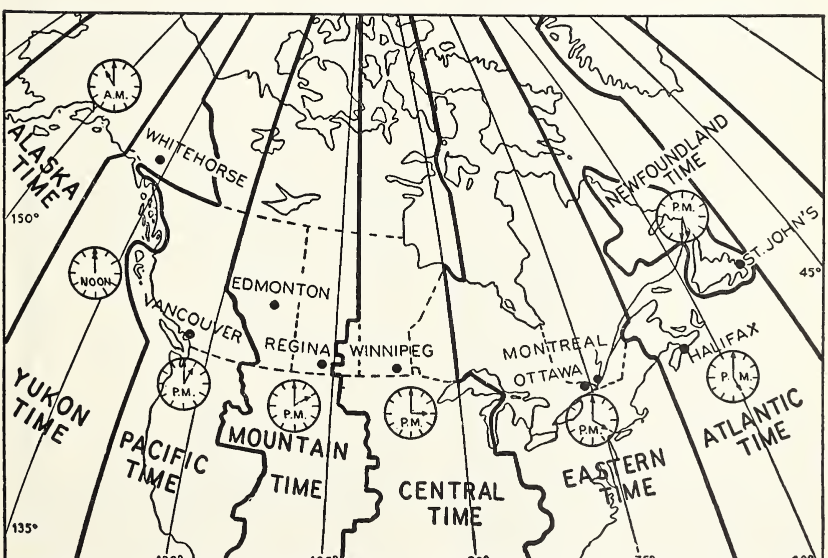


Fig. 22–2. The Standard time belts of Canada are irregular in shape, but the belts must average about 15° longitude in width. Each entire belt keeps the time of its time meridian.

therefore three hours earlier. When it is 5 P.M. in Montreal, it is 2 P.M. in Vancouver.

Most provinces and states in North America use *daylight-saving time* during the late spring and summer months. Clocks are set one hour ahead of standard time so that daylight will end one hour later in the evening. A sunset that would occur at 8:00 P.M. standard time takes place at 9:00 P.M. daylight time. One economy that results from daylight-saving time is the decreased use of electricity for lighting.

In the spring, when we set our clocks ahead for daylight-saving time, we "lose" an hour. The hour is "returned" in the fall, for when we set our clocks back again to standard time, we "gain" an hour.

8. The international date line. A traveler going eastward from one time belt to another also "loses" an hour with each change of time, while a westward traveler "gains" an hour each time he sets his watch back. If either one of these travelers completes a trip around the world, he will have "lost" or "gained" 24 hours, and in his reckoning he will be either a day ahead or a day behind the calendar in the place from which he started. To prevent such confusion, the *international date line* has been established. As the traveler on ship or plane crosses this line, he makes a change of date that compensates for the "losses" or "gains" of time. The *westward traveler* (who has been turning his watch back) *moves his calendar forward,* as from Sunday to Monday. The *eastward traveler* (who has been turning his watch forward) *moves his calendar back,* as from Saturday to Friday.

The international date line is located entirely in the ocean, so all changes of date are made on ship or plane, and no

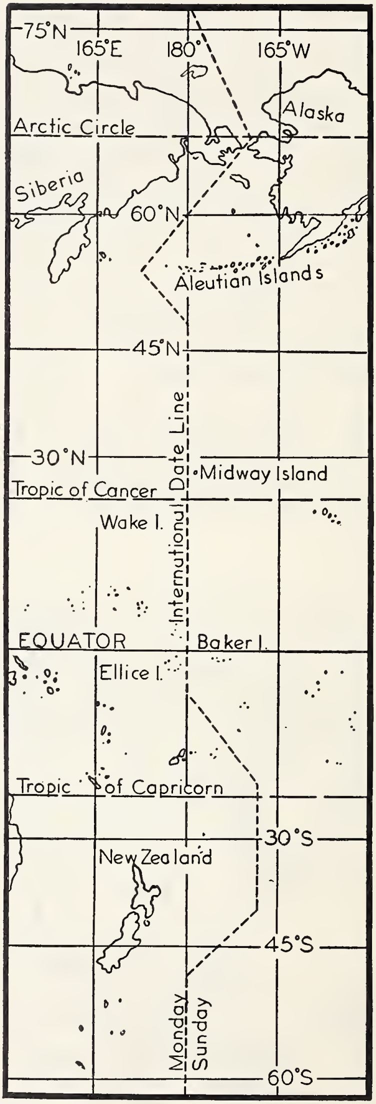


Fig. 22–3. The International Date Line follows the 180° meridian except where "offsets" are necessary to avoid land areas. The date on the west side of the line is one day later than the east side.

body of land is divided by it. For the most part it follows the 180th meridian, except for a few zigzags, or *offsets,* where the meridian runs through eastern Siberia, the Aleutian Islands, and some South Sea islands. At these places the date line swerves away from the 180th meridian and into the sea.

Since the international date line is in the center of a time belt, no change in clock time is made when it is crossed. The change is in the date alone. The western half of this time belt is therefore always exactly one day ahead of the eastern half, and is the part of the world in which each new day has its beginning. With each passing hour, the new date moves westward, one belt at a time, around the earth. There are always two dates on the earth at any moment, and for a good part of our day in the United States, we are behind the date in eastern Asia and the far Pacific islands.

9. A.M. and P.M. A.M. means "antemeridian"; it refers to the 12 hours from midnight to noon during which *the sun is before the meridian.* P.M. means "postmeridian"; it refers to the 12 hours from noon to midnight during which *the sun is after the meridian.* Midnight is called 12 P.M., and noon is distinguished from it by being called 12 M., the time when *the sun is on the meridian.*

It may be well to point out here that in any problems involving the determination of time in various parts of the world, *the date changes when the time becomes either later or earlier than midnight.* For example, when it is 11 P.M. *Thursday* in Vancouver, it is 3 A.M. *Friday* in Halifax.

10. The calendar. A perfect calendar would be one in which the earth reached the same point in its orbit at exactly the same time and date each year. In such a calendar the seasons would begin at the same moment each year. A perfect calendar is almost an impossibility because the earth's rotation period (day) does not fit into its revolution period (year) an even number of times. The exact length of a year is slightly less than 365¼ days.

The early Roman calendar was based on the motions of the moon. Because it did not take into consideration the revolution of the earth around the sun, the seasons began at an earlier date each year. By 46 B.C. spring arrived in December. Julius Caesar reformed the calendar so that the year would represent the time it takes the earth to make one revolution around the sun, that is, 365¼ days. The new calendar, known as the *Julian calendar,* introduced the modern system of three years of 365 days followed by a leap year of 366 days.

But even Caesar's average year of 365¼ days was just a bit too long to match the true year, and the seasons began to "arrive early" again, but not very much too early. In 1582 the spring equinox came on March 11 instead of March 21. At this time Pope Gregory introduced an adjustment which brought the average length of the year very close to its true length. At the same time the spring equinox was dated March 21 again. This *Gregorian calendar* was adopted by Great Britain and the American colonies in 1752, and is in use in most countries of the world today.

In the Gregorian calendar the average length of the year is shortened slightly by omitting three days in every 400 years. To do this, a simple rule is used. Ordinarily every year divisible by 4 is a leap year; thus every century year should also be a leap year. Under the new rule, however, the century year is *not* a leap year *unless its first two numbers are divisible by 4.* In any four successive

centurial years, such as 1800, 1900, 2000, and 2100, there can be only one leap year. In this case it is the year 2000. By thus eliminating three leap years in each period of 400 years, the rule achieves its aim of getting rid of three days in that time.

HAVE YOU LEARNED THESE?

Meanings of: apparent solar day, apparent solar noon, mean solar day, mean solar noon, equation of time, time meridian.

Explanations of: standard time, standard time zones, daylight time, international date line and its rule, A.M., P.M., M., the leap-year rule in the Gregorian calendar, the change-of-time rule in standard time zones.

TOPIC QUESTIONS

Each topic question refers to the topic of the same number within the chapter.

1. (*a*) What is the origin of such units of time as the year, month, day, hour, minute, and second? (*b*) Why are only the year and the day considered to be "natural" units?

2. (*a*) How does an astronomer measure the length of a day? (*b*) Distinguish between a sidereal day and an apparent solar day. (*c*) What is apparent solar noon?

3. (*a*) Why do the lengths of apparent solar days differ? (*b*) How is the mean solar day obtained?

4. (*a*) Explain what is meant by mean solar time, mean solar noon, equation of time, sun fast, sun slow. (*b*) How can the time of apparent solar noon be calculated? Illustrate.

5. (*a*) Explain, with examples, why places that are even short distances east or west of each other have different solar time. (*b*) Why was a standard time system adopted in 1883?

6. (*a*) Explain the standard time system for the whole world. (*b*) Name the 24 time meridians.

7. (*a*) Why do standard time zones have irregular boundaries on land? (*b*) Name the standard time belts of Canada with their time meridians. (*c*) Explain what daylight time is and why it is used.

8. (*a*) Explain why we have an international date line. (*b*) Where is the date line? (*c*) How does a traveler change his calendar when crossing the date line? (*d*) Describe the start and progress of a new date.

9. Explain the meanings of A.M., P.M., and M.

10. (*a*) What is a "perfect calendar," and why is it "almost an impossibility"? (*b*) Why did Julius Caesar discard the old Roman calendar? (*c*) What reform did the Julian calendar introduce? (*d*) What further improvement did the Gregorian calendar introduce?

GENERAL QUESTIONS

1. A sidereal day is 4 minutes shorter than a mean solar day. Why?

2. What is the greatest possible difference between the standard time of a zone and the local time of any place in it? (Assume that the time meridian is exactly in the middle of the zone.) Explain.

3. Name 3 important cities in each of the standard time belts of southern Canada.

4. Why do we not use daylight saving time in winter?

5. What time is it in each Canadian standard time belt when the new date is just beginning at the international date line?

6. Is there a time of day when only one date exists on the earth? Prove your answer.

7. Distinguish between 12:10 A.M. and 12:10 P.M.

8. What are the time and date in Manila, Tokyo, Honolulu, Melbourne,

Buenos Aires, London, Moscow, and Calcutta at 10 P.M. in Washington, D.C.

9. How can an eclipse that began on Saturday end on Friday, as described in the introduction to this chapter?

10. What objection would there be to having the whole earth keep the same hour and date?

STUDENT ACTIVITIES

1. Calculating and observing the moment of apparent solar noon
2. Measuring the length of an apparent solar day (from one apparent solar noon to the next)
3. Reading a sundial
4. Making a sundial

SUPPLEMENTARY TOPICS

1. The History of the Calendar
2. The Proposed "World" Calendar and Other Calendars
3. Why the Solar Day Varies in Length
4. The Sundial
5. The Analemma

See list of suggestions for further reading at the end of Chapter 17.

Appendix

THE RECORD OF THE ROCKS

1. How does the historical geologist know? The historical geologist can describe to you the history of the earth during its last two billion years. He will tell you that there were five great *eras* of earth history, and he will tell you how long each one lasted. He will tell you that the eras were divided into *periods,* and he will tell you how many years each period lasted. He will tell you when the first forms of life developed, what kinds of plants and animals lived during each period, and when man made his appearance on the earth. He will tell you when and where there were hot climates, cold climates, wet climates, or dry climates. He will tell you about ancient Ice Ages, and will draw maps showing continents with strange outlines during past geologic periods. How does the historical geologist know all these things?

The principal events in the geological history of the earth have been summarized by scientists into a *geologic timetable.* In the following paragraphs you shall gain some insight into the methods used by the historical geologist to acquire this knowledge of the earth's history. Historical geology will prove to be a fascinating subject.

2. A sample of earth history. Perhaps it will be easier to understand how the geologist reads earth history if we describe a sample chapter in that history.

As in our own times, weathering and erosion attack the surface of the continents everywhere. The bedrock of the continents is broken and shattered, and the resulting rock fragments are carried down from mountains and highlands by all the agents of erosion, even as they are today. Rivers deposit their sediments in carefully sorted horizontal layers of gravels, sands, and clays. These are deposited on flood plains, on lake floors, and on the shelves of the continents. In time these sediments are consolidated into sedimentary rocks.

Plants and animals live and die in the waters of the lakes and the oceans. As they die, these plants and animals are buried in the accumulating sediments into which they fall. When the sediments form layers of rock, many plants and animals are preserved in them as fossils.

Erosion and deposition continue for millions of years. More and more sediments are deposited. More and more layers of rock are formed. The oldest layers are at the bottom, the most recent ones at the top. In some areas the sediments are hundreds or even thousands of feet in thickness. The mountains and highlands of the continent are being

THE GEOLOGIC TIMETABLE

Earth History and the Development of Life

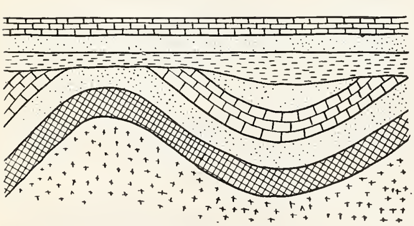
Era	*Period or Epoch Probable Duration*	*Characteristic Life*	*Physical Events*
Cenozoic *The Age of Mammals*	Recent last 25,000 years	Development and dominance of man.	West Coast uplift. Widespread erosion.
	Pleistocene 2 million years (The Great Ice Age)	Early man appears. Modern mammals develop.	Four glacial and interglacial periods.
	Pliocene 10 million years	Mammals appear in increasing varieties and numbers. Early types of our domestic and wild animals appear (deer, bear, dog, cat, horse, elephant).	Formation of Alps and Himalaya Mountains. Uplift of Columbia and Colorado plateaus. Elevation of Rocky and West Coast ranges. Volcanic activity in West. North America.
	Miocene 15 million years		
	Oligocene 10 million years		
	Eocene 20 million years		
Mesozoic *The Age of Reptiles*	Cretaceous 60 million years	Dinosaurs become extinct. Birds, mammals, and modern flowering plants appear.	Rocky Mountain uplift begins. Western coal swamps form during widespread submergence before mountains rise.
	Jurassic 30 million years	Dinosaurs dominate. First birds, insects, and modern trees appear.	Sierra Nevada and West Coastal Mountains begin to rise.
	Triassic 30 million years	Reptiles, medieval plants, and first mammals appear.	Igneous activity in the Maritime provinces.
Paleozoic *The Age of Invertebrates*	Permian 50 million years	Trilobites and other invertebrates disappear. Rise of seed plants and reptiles.	Appalachian Mountains formed; worldwide mountain-making. General arid conditions.
	Pennsylvanian 40 million years	Reptiles first appear; insects become numerous.	Coal-forming swamps; land rises and falls.
	Mississippian 30 million years	First land vertebrates; amphibians and crinoids numerous; ferns and conifers common.	General submergence of the continents.
	Devonian 40 million years	First land plants and amphibians: age of fishes.	Mountains formed in New England and Canada. Vulcanism in New England.
	Silurian 30 million years	First lungfishes, scorpions, and land plants. Corals abundant.	Great volcanic activity. Widespread erosion and submergence inland.
	Ordovician 60 million years	First vertebrates (fish) appear.	Mountains formed in Quebec E. Townships.
	Cambrian 100 million years	Invertebrates dominate (trilobites).	Widespread deposition.
Proterozoic	500 million years	Primitive invertebrates without shells: algae, worm tracks, sponges, and graphite deposits.	Extensive lava flows; glaciation, metamorphism of rocks.
Archeozoic	1000 million years	Flakes of graphite in schists and gneisses; one-celled forms of marine life (algae).	Some mountain building and considerable volcanic activity.

worn down, the shallow areas of the ocean are being filled in.

And then one day great changes begin. The long-sleeping forces within the earth awaken. Volcanic activity and crustal movements raise extensive sections of the surface high above their former levels. Great mountain ranges are created. Horizontal rock layers are folded, tilted, domed, or intruded by lava. Sedimentary rocks may be metamorphosed. With changing topography and climate, many forms of life die out while others are evolved. From within the earth has come a *revolution,* as the geologist calls it, to end an era of earth history.

No sooner are the new highlands and mountains created than they too begin to be attacked by weathering and erosion, and a new era begins. Again long intervals of time pass. Eroded areas in coastal regions may be submerged by the sea. Sediments may be deposited on the eroded surfaces of folded or tilted rocks.

The new sediments are in horizontal layers. It can easily be seen that they do not belong to the same period in earth history as the rocks on which they rest. The rocks beneath are folded or tilted; they may be metamorphosed and intruded by lava; they contain different fossils; their surface is weathered and eroded. They do not conform or fit in with the younger rocks resting on them. The geologist calls such an arrangement of rocks of two different ages of earth history an *unconformity.*



An unconformity.

3. Which rocks are oldest? The relative age of the sedimentary rocks in any one area is easily determined. The oldest layer is at the bottom. The youngest or most recently formed layer is at the top. Any igneous intrusions—dikes, sills, or laccoliths—must have come after the sedimentary rocks were formed. Igneous intrusions are therefore obviously younger than the rocks into which they have intruded.

In volcanic regions lava flows and volcanic cones may lie on top of other rocks. Here, too, the lavas are obviously younger than the rocks on which they rest, and the youngest layers of lava are the top ones.

The relative age of sedimentary rocks in different areas can usually be determined by the fossils they contain, and to some extent by how consolidated their sediments have become. For example, the sediments of the Atlantic Coastal Plain are still largely unconsolidated. The older sediments of the Great Plains are now layers of solid rock.

In general, metamorphic rocks—such as those of the Piedmont and New England mountain areas—are older than sedimentary rocks. In fact, the metamorphic rocks include some of the oldest of all the surface rocks of the earth.

4. How do we know there were five eras? In Topic 2 it was explained that eras are ended by geological *revolutions.* In these, extensive volcanic activity and uplift produce great changes in the physical appearance of the earth and in the forms of its plant and animal life. The historical geologist recognizes these revolutions through unconformities, through different rock formations, and through marked differences in the fossils of these different rocks. From his studies of

these features he has come to the conclusion that there were five great eras of earth history.

The five eras are given names that indicate the kind of life that existed in them. The oldest era is the Archeozoic (very ancient life) era. It ended with the Laurentian-Algoman revolution which produced the Laurentian Mountains of Canada, the Adirondack Mountains of New York, and mountains in the Great Lakes region.

The Proterozoic (earlier life) era ended with the Killarney-Grand Canyon revolution which formed mountains in the Lake Superior region and in many other parts of the earth. The Paleozoic (ancient life) era, also known as the Age of Invertebrates, ended with the Appalachian revolution in which the Appalachian Mountains were created.

Then came the Mesozoic (middle life) era, also known as the Age of Reptiles. This was the era in which the dinosaurs lived. The Laramide revolution brought this era to a close, creating the Rocky Mountains and re-elevating the nearly peneplaned Appalachian Mountains.

The Cenozoic (recent life) era, also known as the Age of Mammals is the latest of the five great eras of earth history. Most geologists regard the Cenozoic era as still with us. Others prefer to see our present time as the start of the Psychozoic (mind-life) era. The latter part of the Cenozoic era has been marked by a continuing Cascade revolution. Though creating no new mountains in North America, the Cascade revolution has added considerable height to the mountains of western United States. It has also raised the Appalachian Mountains slightly.

5. How are eras divided into periods? The Paleozoic and Mesozoic eras appear to have consisted of a number of distinct divisions which the geologist now calls *periods.* Like eras, periods differ from each other in such characteristics as the relative position of land and sea, the kinds of climates, and the forms of plant and animal life. However, the differences between two successive periods are not as great as those between two successive eras.

While eras are separated by revolutions, periods are separated by *disturbances.* These are similar to revolutions, but the changes they produce in topography, climate, and forms of life are not as widespread or as drastic. In the rocks, disturbances can be identified by unconformities similar to those of revolutions.

Both revolutions and disturbances are described briefly in the *physical events* column of our geological timetable. Disturbances, like revolutions, are usually named for some prominent feature they produce. For example, the Palisade disturbance at the close of the Triassic period formed a lava sill which later became the famous Palisades of the Hudson River.

6. What are epochs? The rock record of the Cenozoic era shows a number of divisions that are shorter and less distinct than the divisions of the Paleozoic and Mesozoic eras. The geologist prefers to call these *epochs* rather than periods. We are now living in the Recent epoch which began when the Great Ice Age ended about 25,000 years ago. The Ice Age itself occurred during the Pleistocene epoch.

7. How the life of the past was recorded. The geologist is able to tell us what living things existed in past ages because he has found their record in the rocks. This record consists of fossils, which are the remains or impressions of plants and animals preserved in the

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The woolly mammoth was a common inhabitant of Eurasia and North America about 25,000 years ago at the close of the Ice Age.

rocks. With this record the geologist is able to trace the evolution of life on the earth from the simple beginnings of Archeozoic or Proterozoic time to the highly developed forms of today.

The formation of a fossil has been described briefly in Topic 2 of this chapter and in Topic 11 of Chapter 3. There are four principal kinds of fossils, as follows:

(*a*) *Original remains.* In some cases fossils represent the actual remains of plants or animals. The entire bodies of woolly mammoths, great elephant-like creatures of Pleistocene time, have been found almost perfectly preserved in the perpetually frozen earth of Siberia. Here they were trapped in glacial moraines at the close of the Ice Age many thousands of years ago.

On the shores of the Baltic Sea in Europe, insects of millions of years ago have been found perfectly preserved in the hardened resin of pine trees on which they crawled. This hardened resin is what we call *amber*. Other examples of original materials are the shells of shellfish which became consolidated to form fossil varieties of limestone, and the bones and teeth of dinosaurs and other animals of the past.

(*b*) *Replaced remains.* Many fossils no longer contain the original materials of which they were made, although they may look unchanged. Ground water may replace the lime of shells and bones with such minerals as silica and iron pyrites. The petrified trees of Arizona were formed when ground water slowly replaced the decaying wood of these buried trees with silica.

(*c*) *Molds and casts.* Sometimes a fossil shell or bone is completely dissolved out of the rock in which it was preserved. This leaves a hollow *mold* which shows only what the shape of the fossil had been. The filling of such a mold with new mineral material may produce a *cast* of the original fossil. Molds and casts of shellfish are common fossils. The molds of ferns, leaves, and fish are also found in many rocks.

(*d*) *Impressions.* Even the impressions left in the muds and sands of flood plains and deltas by moving animals may be preserved when the sediments become rock. In such shales and sandstones, geologists have found the footprints of dinosaurs, the trails of ancient

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This member of the dinosaur group of Mesozoic time (*stegosaurus*) was armed with a double row of plates and spines down his back. (*Restoration by Charles R. Knight.*)

worms, and many other impressions of living things of the past.

8. What are index fossils? Fossils that are typical of a particular period or epoch of earth history are very useful to the historical geologist. When he finds one of these fossils in a layer of rock, no matter in what part of the world, it immediately tells him the geological age of the rock. These *index fossils* help to correlate the geological histories of different parts of the United States or of different continents.

Index fossils are a great aid to the oil geologist. Suppose he knows that many oil deposits have been found in the rocks of a particular geologic period. In seeking new oil deposits he uses his knowledge of the index fossils of this period in helping him to identify other rock formations of the same geological period.

Ward's Natural Science Establishment, Inc.

Fossil trilobite embedded in rock.

9. Calculating the actual length of a period. The historical geologist does not hesitate to tell us how long ago certain geological events occurred, or how long each division of the earth's history lasted. How does he calculate the duration of geological time? Let us examine a few samples of his methods.

(*a*) *Rate of deposition.* Geologists have made careful studies to determine the rates at which sediments are deposited on the continental shelves. Rates of deposition vary widely. On the average, however, it seems to take between 4000 years and 10,000 years for a layer of sedimentary rock 1 foot thick to be formed.

Suppose it is found that the total

thickness of rock deposited during a single geological period was 6000 feet. At the rate of 1 foot in 5000 years, this would mean that deposition had been going on for 6000 × 5000 years, or 30,000,000 years of this period.

(*b*) *Rate of erosion.* The rate of erosion probably varies even more than the rate of deposition. Again, however, careful studies of rivers show that a rate of erosion of 1 foot of land in 5000 years may be taken as an average rate. Using this figure, the geologist may calculate the time taken by the Colorado River to erode its canyon 4000 feet deep. Multiplying 4000 by 5000 years, he gets a total of 20,000,000 years—more or less! Of course such calculations are not exact, but they have a basis in scientific studies of actual facts, and must be fairly close to the truth. They are not guesses.

(*c*) *Radioactivity.* The most recent method of calculating the age of a particular rock formation—and from this the time when it was formed—is based on radioactivity. Small amounts of radioactive elements such as uranium and thorium occur in igneous rocks. Through the ages, the radiations given off by uranium atoms cause them to change into lead at a very slow but absolutely definite rate known to the geologist. By measuring the ratio of lead to uranium in an igneous rock, the geologist can calculate the age of the rock and the approximate time of its origin. (Lead formed from uranium is slightly different from ordinary lead and can easily be distinguished from it.)

Measurements by this method show the oldest rocks in the United States to be about 2 billion years old. Rocks of even greater age occur in South Africa.

(*d*) *Salt in the ocean.* Attempts have been made to determine the age of the earth by calculating the age of its ocean. To do this, geologists first calculate how much salt there is in the entire ocean. Then they estimate how much salt is being carried into the ocean by all the rivers of the world each year. From these two figures it is possible to calculate how long it took for the ocean to acquire its salt. This method can give us no exact answer, however, since the rate of salt accumulation must have varied widely through the ages. Using a rate close to that of today, we obtain an answer of about 500,000,000 years.

10. Other ways of measuring geological time. In Topic 9 we explained how the geologist measures the duration of periods that are millions of years long. But how does he know that the Ice Age ended only about 25,000 years ago? How does he know that Niagara Falls was born about 25,000 years ago? How does he measure such shorter periods of time?

A botanist can determine the age of a tree by actually counting the annual rings in its trunk. In much the same way the geologist finds out when the Ice Age ended in the United States. Instead of counting annual rings, he counts the layers of sediment deposited each year by the retreating glacier.

Wherever lakes occurred at the ice front, streams from the melting ice deposited layers of sediment on the lake floors. These sediments were thicker and coarser in spring and summer than in fall and winter, because more rapid melting of the glacier in spring and summer made the outwash streams larger, faster, and able to carry more and heavier particles. Thus each year two distinct layers of sediment were deposited. The spring-summer layer was coarse and thick; the fall-winter layer was fine and thin.

The layers of sediment consisted

American Museum of Natural History

This is a geological artist's conception of the appearance of the coal-forming forests that existed on the earth in the Pennsylvanian period of the Paleozoic era. These forests were dominated by gigantic ferns, rushes, and club mosses.

largely of clays, called varved (banded) clays or simply *varves*. Each pair of varves represents the deposits of a single year. By careful and painstaking research, specialists in glacial geology have traced glacial lake deposits from the extreme southern positions of the ice sheets in Europe and North America all the way north to the polar regions. An actual count of varves tells us that about 25,000 years have elapsed since the ice sheets retreated from southern New York State.

The age of Niagara Falls is estimated in the following way. Niagara is known to have originated at Lewiston, New York, from where it has receded 7 miles to its present position. Knowing the rate at which Niagara is receding today, the geologist estimates its average rate of recession since its origin. From this he can calculate how long it has taken to recede 7 miles. This figure, too, is simply a reasonable estimate. Niagara Falls is known to have originated during the close of the Ice Age, so this estimate can also be used to tell us when the Ice Age was ending.

11. Clues to climates of the past. The geologist can often read the climates of past ages from the rocks. Deposits of coral limestone tell us of warm climates, for corals grow only in waters whose temperature is always at least 68° F. Deposits of consolidated glacial tills (called *tillites*) in equatorial Africa tell us of the existence of ice ages and glacial climates hundreds of millions of years ago.

Thick deposits of salt and gypsum, which could have been formed only by long continued evaporation, tell us of ancient ages of hot dry climates. Coal beds in Antarctica are a sure sign that temperate or tropical climates existed there in some extended period of long ago. These are but a few of the more obvious indicators of the climates of the past.

HAVE YOU LEARNED THESE?

Meanings of: era, period, epoch, revolution, unconformity, disturbance, fossil, varve

Explanations of: the relative age of rocks; why there were five eras; the formation of fossils; use of index fossils; calculating geologic time; determining past climates

TOPIC QUESTIONS

1. What information about the earth's past does the historical geologist give us? What is the geologic timetable?

2. Summarize the principal events in the geological history of an era. What is a revolution? What is an unconformity?

3. (*a*) How do we determine the relative age of sedimentary and igneous rocks in a particular area? (*b*) How do we determine the relative age of rocks in different areas?

4. (*a*) How do we know there were five eras of earth history? (*b*) Referring to the geologic timetable, describe the principal features of the five eras.

5. (*a*) Explain how eras are divided into periods. (*b*) What is a disturbance?

6. (*a*) What is an epoch? (*b*) Why is the Cenozoic era divided into epochs rather than periods?

7. (*a*) What is a fossil? (*b*) How is a fossil formed? (*c*) Give a brief explanation of the four principal kinds of fossils.

8. (*a*) What is an index fossil? (*b*) What use do geologists make of index fossils?

9. Describe three different methods used to determine the duration of geological time.

10. (*a*) Explain what varves are and how they are used in determining the end of the Ice Age. (*b*) How is the age of Niagara Falls measured?

11. Describe the evidences that provide clues to the climates of the past.

GENERAL QUESTIONS

1. How does the geologist know what the outlines of the continents were during past ages?

2. Why are metamorphic rocks likely to be older than sedimentary rocks?

3. What factors would cause variations in the rates of deposition during a geological era? of erosion?

4. Why are the methods of radioactivity less useful for determining the ages of sedimentary or metamorphic rocks than for igneous rocks?

5. What factors may have caused the rate of salt accumulation in the ocean to vary through the ages?

6. Summer varves are usually reddish or brownish in color because of greater weathering by oxygen. Explain this.

7. Fall-winter varves are usually blackish because they contain more organic matter than spring-summer varves. Why?

8. What evidences of glaciation would be found in tillites?

9. Referring to the geologic timetable, make a list of the mountains and plateaus of the United States, giving the period of formation of each. Arrange them according to relative age.

10. The geologic timetable says that there were four glacial periods during the Pleistocene epoch. What evidences might indicate this?

11. The Mississippian and Pennsylvanian periods are often put together as the Carboniferous period. Why? (See the geologic timetable.)

12. In what way are the flakes of graphite found in Archeozoic schists and gneisses (see the geologic timetable) possible indicators that life existed in that era?

STUDENT ACTIVITIES

1. Studying exhibits of fossils in museums
2. Hunting fossils in the locality
3. Making a collection of fossils
4. Going on field trips to determine the relative age of local rock formations
5. Determining the geological age of local rock formations
6. Collecting pictures of prehistoric plants and animals

SUPPLEMENTARY TOPICS

1. The Evolution of Man in the Pleistocene Epoch
2. The Carboniferous Period
3. The Origin of Petroleum
4. The Age of Dinosaurs
5. The Mammals of the Cenozoic Era
6. The Origin of the Great Salt Deposits

SUGGESTIONS FOR FURTHER READING

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